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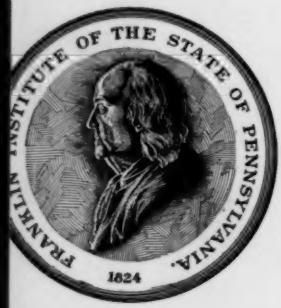

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Beyond the Air Age
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Research—Foundation of Steel's Progress Today
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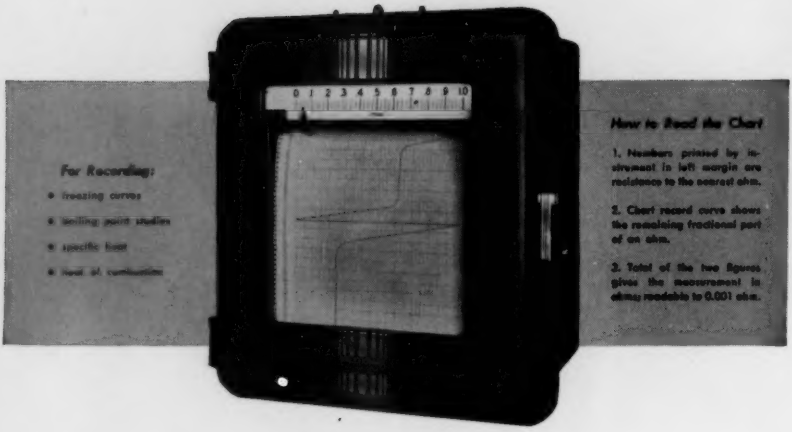

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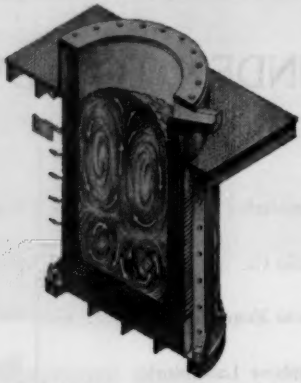

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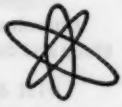

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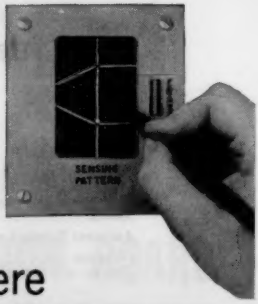

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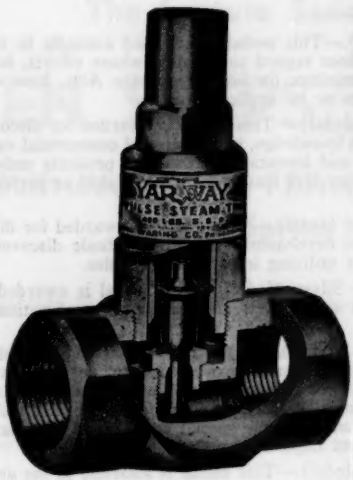

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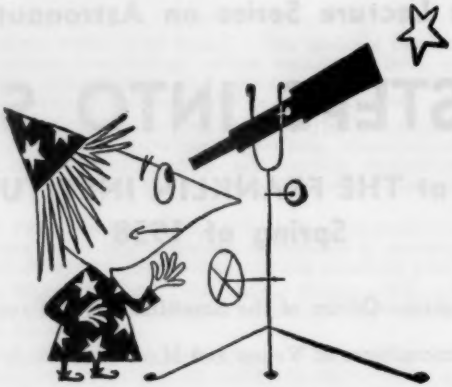

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BY

JOHN B. MEDARIS [1]

Barring unexpected success in the field of international relations, the universe could become the battlefield of the future. The only positive means of preventing such a disastrous future is for this nation to achieve the earliest manned control of space in the interest of those high principles of human welfare which have always directed our progress.

It is that challenge which I put to you tonight. In doing so I will discuss the compelling reasons which, in my opinion, dictate a national program which has the mastery of space as its ultimate goal. These considerations occupy the close attention of our Government, the armed services, a substantial portion of American science and industry, and those of our people who understand the real threat posed by a potential aggressor whose technological programs are directed towards the same end, albeit for very different purposes. The blunt truth is that we are in a race against time with an adversary of no mean capabilities, who has committed to his effort a far greater percentage of his total resources than we have so far mustered.

Physical control of man's environment, and the uses to which that control has been put, mark the course of history. Maritime powers sought domination of the seas in the Ages of Sail and Steam. The Air Age witnessed a comparable struggle of men and machines for control of the sensible atmosphere and the lands beneath it. We are moving beyond the Air Age into the Age of Space, still employing men and machines—but machines of very advanced design responsive to automatic

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(Note—The Franklin Institute is not responsible for the statements and opinions advanced by contributors in the JOURNAL.)

control. New capabilities are being demonstrated almost daily through the launching of orbital satellites and of long-range ballistic missiles.

A satellite capability of increasing magnitude places at the disposal of its owner the power to exercise continuing reconnaissance over every point on earth, the power to launch and guide weapons of thermonuclear or any other type to an accurate strike on any target and the power to monitor on equal terms any other occupants of space. Thus all the continents, islands and seas would be at the mercy of an all-seeing eye immune to interruption from any earth-bound quarter. We know today that these impressive devices are within the known state of the art. The question becomes one of time, first; and of the scope of effort and applied resources, secondly.

Employed for peaceful pursuits, the same type of space vehicles can efficiently serve human needs by making possible weather forecasts more accurate than ever have been available, and by providing communications media more efficient and more rapid than can be attained by any other means. They can provide scientific data about our environment not otherwise available. They can furnish bases from which to explore the planets and the distant reaches of the heavens. Again, the question is not whether this capability will be attained, but by whom, and when.

Satellites and outer space vehicles are close technological relatives of the modern weapons systems we are developing as intermediate range and intercontinental ballistic missiles. The same propulsive systems, and much the same order of efficiency in guidance and control systems, will serve initially the weapon, the scientific investigation, and the space vehicle.

I have mentioned the complexity of long-range missile systems. Their development requires major engineering undertakings. Normally from 5 to 6 years are required to carry such a project from inception to deployment of the missile in the field, including the provision of ground handling equipment, other auxiliary equipment and the training of troops. In the continuing struggle between offense and defense, the missile must exploit the fullest capabilities of technology at the time of use. It is not enough to base the original design and initial development upon existing technology; instead, it must be based upon an extrapolation of this technology against the time when it will be useful as a weapon. Otherwise, the missile system will become obsolescent and ineffective before it reaches the field.

Furthermore, if our missile programs are to remain ahead of enemy countermeasures, we must constantly push technological frontiers forward, to provide an adequate foundation for improved future designs. Essential to this process are basic and applied research. I use the term "basic" in the sense of seeking fundamental knowledge without regard to specific application and "applied" as the process of utilizing new prin-

ciples to develop and prove advanced types of components and subsystems. In other words, the basic research of today should be adequate to provide answers that will lead to efficient new applications 15 years hence. In the intermediate area of applied research, we should today be perfecting tools which will be useful 5 to 10 years from now. The development of end products, such as long-range weapons and new space systems should be concentrated upon those needed items that can be brought into use within 3 to 5 years.

End product development itself should be straight-forward engineering based on already established fundamental information and proven component principles. All too often the needed basic and applied research has not been done in this relatively new art, for lack of funds or lack of imagination, and the systems engineering is complicated and delayed by the need to conduct such research on a coincidental time scale. This entails inordinately expensive duplication of effort. Duplication in basic and applied research areas may be good, economical and acceptable—but should certainly not be required in actual missile engineering. The cost of research is relatively minor, but these costs skyrocket as we approach the engineering end of the spectrum and commit substantial amounts of manpower, material, funds and tooling. Money and time are actually saved, in the long run, by increased effort in basic, and particularly, applied research.

It should be a source of civic pride to know that in Philadelphia you have three major activities highly competent in basic and applied research related to the Army's missile programs. Our host installation, The Franklin Institute, Temple University, and Frankford Arsenal of the Army Ordnance Corps have all made significant contributions and have broad potentials for still greater achievements in the future. It is appropriate that we recognize some of these endeavors.

Franklin Institute has made two important contributions to the development of the *Jupiter* Intermediate Range Ballistic Missile.

The first is an essential component of the control system. Basic to the *Jupiter* all-inertial guidance system is a stabilized platform relative to which deviations are measured by sensing devices carried onboard the missile. Necessary corrections in flight to overcome external forces are achieved by deflecting the engine to change the line of thrust—a kind of steering mechanism. One of the most vital elements in the overall control system is the mechanism which deflects the engine in response to signals from the guidance system.

This consists of an hydraulic actuator system with the necessary servo-mechanism for producing stable motion consistent with the guidance instruction. The actuators themselves must produce a relatively high thrust of approximately 10,000 pounds. They must be capable of producing an engine deflection at a maximum rate of 30 degrees per second. This deflection, in turn, must be precisely controlled to within

one-tenth of a degree or better. The maximum travel of the actuators is 6 in., equivalent to plus or minus 7 degrees of engine swivel. However, the required deflection in actual flight is only plus or minus 1 degree so that the accuracy of positioning must be quite high. Developed by Franklin Institute, this actuator system has been successful and has been flight-tested.

A closely related element of the missile system is the equipment which tests the actuator system and the over-all control mechanism. Also developed by Franklin Institute, this is an hydraulic system which simulates the offset thrust vector and the moment of inertia of the rocket motor. Used in conjunction with an analog computer, it permits simulation of missile flight before the missile is flown and so makes it possible to determine in laboratory tests the behavior of the control system throughout the entire, full-range flight of 1500 miles.

The second important area in which the Institute has supported Army missile development concerns the problem of testing equipment under high accelerations of launching, and the weightless conditions of ballistic flight.

As soon as the thrust of the missile is terminated and the missile begins to react freely under the influence of gravity, the equipment on board must function under a condition of essential weightlessness. It is imperative that all of the complex guidance and control devices perform satisfactorily under such conditions, and so their performance must be thoroughly tested in the laboratory. Franklin Institute participated in the development of a test device for achieving both high accelerations and weightlessness for short periods of time.

We know the device as a "guillotine." It provides for testing of components up to about 15 or 20 pounds weight under conditions of high acceleration and free flight. It consists essentially of an air piston system to propel a test table vertically and to catch it on an air cushion as it falls. This process is repeated at a controlled frequency which determines the acceleration achieved and the height of fall. Accelerations up to approximately 20 g's can be achieved with a repetition frequency of approximately one cycle per second. An essential part of any such device is, of course, the associated servo system for control and stability.

Temple University Research Institute has been doing valuable work in the field of high temperatures produced by chemical heat. This is of the utmost importance to our missile programs from two separate standpoints. One concerns the aerodynamic heating of the nose cone on reentry into the atmosphere, and the other concerns the resistance of materials to the high temperatures developed in rocket engines of considerable thrust.

Temple's endeavors have been concerned with such basic physical problems as the behavior of solids and gases under high temperature

conditions. This involves problems of dissociation and association of gases, heat transfer, radiation properties and resistance to melting and oxidation.

By burning cyanogen, temperatures up to 4000° or 5000° C. have been achieved on a usable laboratory scale. Subjection of test samples of various materials to the high temperature flame has given valuable data concerning material properties. Even higher temperatures have been achieved on a much smaller scale by the use of special types of electric arcs. These are of particular value in studies of gas behavior and may well develop into broader applications.

Temple has also contributed in another significant basic science area. This has been the development of a simple, compact, minute device for detection of micrometeorites. This was used for important data collection on our first artificial satellite successfully launched last week.

The third Philadelphia activity mentioned, Frankford Arsenal, has long been a major Ordnance research center. For a period of something less than two weeks in 1952, upon my return from the Argentine where I headed the first U. S. Army Mission to that country, I was Frankford's deputy commander. Then I was ordered into the Pentagon and, to my regret, I never got back to duty here.

Frankford's contribution to our missile projects has been outstanding in the field of materials, especially metallurgical research. One problem confronting the missile designer is the ever-present need for minimum weight and maximum strength. A recently developed aluminum-magnesium alloy provides high strength and excellent weldability in sheet form. However, 100 per cent weld reliability is essential in the fabrication of missile tanks. To achieve this order of reliability, it is necessary to have high compatibility between the sheet material and the casting alloys used for flanges. A completely satisfactory aluminum casting alloy has not yet been found.

It is in the search for such a casting alloy that Frankford is carrying on significant research. The Arsenal has been testing available alloys to determine their characteristics and on the basis of such testing and previous experience has devised new experimental compositions to yield improved characteristics.

A second area in which Frankford has rendered assistance is that of digital computers for fire-control purposes. In the launching of a large ballistic missile, such as the Army *Redstone* or the *Jupiter*, the launching point and the target point pre-determine the necessary settings of the all-inertial guidance system prior to launching. The specific values to be set into the missile depend upon the longitude, the latitude and the altitude of these two points. Second order corrections are possible in terms of wind and gravitational variations. It is obviously impossible to tabulate the settings for an infinity of possible combinations of target and firing point locations. They must be computed in the field.

Basically the process consists of solving a set of several simultaneous equations. This can be done manually, using ordinary desk calculators, but the time required is not acceptable when employing missiles in combat. It is therefore necessary to have available a suitable electronic computer, operable under field conditions and yielding data in an incredibly short interval.

The Arsenal, drawing upon its vast experience in the development of fire-control computers for artillery purposes, has conducted a feasibility study on the basis of which specifications have been drafted for such a computer. A definite recommendation has been submitted for its development.

Another problem associated with firings of large missiles is that of orienting the vehicle on the launching pad before firing. This requires a high degree of accuracy to line up the missile in the proper firing direction. The Arsenal has devised a method of performing this task and has developed some of the related optical components.

Frankford's experience in optical applications has also been utilized in the investigation of high visibility payloads for a satellite system. A major concern in any satellite undertaking is the adequate determination of orbit. Precise orbital information must be secured for the evaluation of certain types of scientific data. Many approaches to providing much greater visibility for the same mass have been and are being considered and investigated.

It is patently impossible in the time available to review in detail either the actual or potential contributions of such broadly competent research and development activities as Franklin Institute, Temple University and Frankford Arsenal. I have described some aspects briefly in an attempt to indicate the over-all scope of this work. The potential for future contributions is almost limitless. It is not feasible at any time to predict with certainty the specific research which could make vital contributions to future development programs. If one could do just that, it would not be research—rather, it would be straight-forward engineering. It is possible only to define certain broad areas in which we know that research must be done to provide the necessary technology which is a prerequisite to future systems. We can define areas in which we do not have enough information. Other related areas, and there are many of them, must be investigated to provide such data. Still others which cannot be specified can be expected, on a statistical basis, to provide useful information.

As we push, at an accelerated pace, into the Age of Space it is wholly possible to define the broad parameters of areas requiring intensified and continuing investigation. A partial list will include microminiaturization of components, improvement of materials, improvement of tracking systems, new solid and liquid fuel propellants, more efficient methods of converting heat energy into electric energy, the large-scale direct trans-

formation of matter into energy, the efficient storage of electric energy, miniature chemical amplifiers and memory devices comparable to those found in man, stabilization of free radicals and investigation of the properties of gravitational fields. Progress in these areas will solve visible problems, and introduce new questions pointing to further investigation.

The only thing of which we can be sure is that the more areas investigated, and the more effort and resources devoted to basic and applied research, the more rapidly our technology will advance and the more effective will become our weapons and space systems. Intensified effort points the way to maximum economy in time and effort required for final engineering development, and the production of useful and modern devices.

I have little patience with those who ask why we must do these things, admittedly costly and not always of measurable or immediate economic value. As I indicated earlier, others are moving in parallel and at a rate of advance which will outdo our effort unless we accelerate immediately, and continue at such a pace as will achieve and maintain the essential advantage of momentum. The overriding priority today should be on the attainment of a space capability at the earliest possible date. So long as our objectives are generally of relatively short-term and immediate nature, we cannot hold our own in this race for survival. We must establish long-range goals 10 to 15 years in the future, and work towards those objectives constantly.

If we reach out as far as we can, to the limits of our vision, the by-products of immediate utility and necessity will come more quickly, more easily, and cheaper, whether these are ballistic missiles, satellite orbiters or other kinds of space vehicles and advanced weapons systems.

It would be a grave error to conclude on a note of pessimism. There has been a healthy re-examination of our research and weapons development programs in recent weeks, out of which have come important firm decisions. I believe we may anticipate continued improvement in the areas of decision and funding. We will get the weapons systems necessary to our defense, of that there can be no question. The point I want to make is that weapons alone, as end items, will not guarantee our security in the eventful years which stretch before us. The technology created out of these military efforts will provide the solid foundation for those other programs which may, in the wrong hands, become weapons and which, in our hands, may yield untold benefits to this and future generations.

Science and technology are advancing at a constantly accelerating rate. We have come to the point where there are greater challenges to our imagination than to our ingenuity. We are presented with a clear and challenging opportunity. We can push forward and outward toward the opening of new frontiers, beyond which our children and our children's children can enter upon new vistas of human progress, new

means for resolving the essential conflicts created by population growth, and new understanding of man's relationship with the infinity of Divine Creation. If we fail to meet this challenge, however, we can find progress preempted by the acknowledged agents of the anti-Christ, with consequences too awful to contemplate. We must accept the challenge, and by equipping our children with the fundamental knowledge demanded by this unfolding future, place them in position to carry on—comprehending the beauty and order of the laws that govern the universe and amendable to their influence as the laws which will govern their lives. We may thus expect them to attain to that understanding that is an essential predicate to human happiness—the understanding of total human self-government in accordance with God's will.

ELASTIC-PLASTIC ANALYSIS OF SCABBING IN MATERIALS

BY

SUDHIR KUMAR [1] AND NORMAN DAVIDS [1]

ABSTRACT

This paper continues the analysis of scabbing in materials in terms of wave propagation effects due to the presence of plasticity. It presents the elastic and the elasto-plastic analysis of stress states which can cause scabbing. A particular problem is solved for scabbing in a bar of 14S-T4 aluminum using a triangular pressure pulse of peak intensity slightly more than twice the yield stress and duration 50 microseconds. One 4-in. scab is obtained by the elastic analysis, none by the elasto-plastic, confirming that plastic flow tends to prevent scabbing. Some of the general implications of the method are discussed.

1. INTRODUCTION

This paper is a continuation of an initial study of scabbing made by the authors and described in a recent issue of this JOURNAL (1).[2] It takes into account wave propagation effects arising from the elastic-plastic behavior of materials, and gives some specific methods of solution for bars. Further research is in progress dealing with the analysis of plates.

As previously explained, the term "scab" refers to the pieces of various shapes and sizes, which fracture or tend to fracture from a solid material when a sudden pressure of high intensity, such as an explosion, is applied. The phenomenon itself is called "scabbing." It is becoming more and more important recently because of the sudden high accelerations and retardations required in various engineering designs in addition to its significance in armor development. An exact analysis of such a phenomenon is almost an impossibility even with the simplest boundary conditions because of a number of factors involved which are not quantitatively known or understood as yet. Among these, the main factors are (*i*) the behavior of materials under dynamic loads and combined stresses (2) (*ii*) hysteresis and thermal losses and (*iii*) dispersion of impact pulses during propagation, especially in the plastic range. However, in order to obtain approximate solutions, it is usually customary to make simplifying assumptions with respect to the above factors. Since the propagation of impact pulses is usually for very short durations in most of the engineering situations that we come across, factors (*ii*) and (*iii*) may be neglected. However, factor (*i*) is quite significant and certain approximations which may take its effects into account should be considered desirable. As is well known for many materials

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[2] The boldface numbers in parentheses refer to the references appended to this paper.

such as hardened steel, the stress-strain curve with higher strain rates tends to approach closer and closer to the continuation of the elastic straight line (2). Thus it might not be considered as being too poor an approximation to assume it as completely straight up to fracture for extremely high rates of loading, thereby applying a completely elastic analysis for the determination of scab lengths. The other way, of course, is to assume that a certain elastic-plastic stress-strain relation (which can be chosen as the static relation itself as a particular case) holds for dynamic loads. Here we will analyze the problem of scabbing in a bar from both approaches, compare the results in order to investigate the possibilities of scabbing, and see which one is closer to reality. It may be mentioned that bars are chosen as the subjects of this study because of the relative simplicity of assumed plane stress. However, the approach can also be extended to an analysis in plates on similar lines by assuming plane strain.

2. SIMPLE ELASTIC ANALYSIS

Most materials are stronger in compression than in tension. Hence, if a strong compressive pulse is generated by some device such as an explosion or impact on a specimen with its other end free, it will be reflected from the free end as a tensile pulse which may be strong enough to create fractures causing scabs. The determination of the scab lengths is greatly simplified if we assume that the stress-strain relation is linear, because then all parts of the pulse at different stress levels are propagated with the same velocity. It follows from this that the pulse shape is retained. Thus, if in a particular case the pulse shape and the strengths S_c, S_t of the material in compression and tension respectively are given or determined experimentally, the determination of scab lengths is reduced to a mere geometrical operation of drawing a few parallel lines and reading off the intercepts (1).

In Fig. 1 is shown a triangular pulse, before reflection and during reflection, close to the free end of a rod. The dotted lines in Fig. 1*ii* are construction lines and the solid lines indicate the resulting shape of the pulse. When the tensile stress AB becomes equal to the strength S_t of the material, the first fracture takes place, causing the first scab. The remaining triangular part of the initial pulse again becomes reflected and the same process repeats until the reflected tensile stresses become less than S_t. Thus, in order to determine the scab lengths, we draw horizontal lines from intercepts of height S_t each, starting from the top of the ordinate in the triangular pulse (Fig. 2) and project their points of intersection on the abscissa. Twice the length of each scab, that is, $2l_1$, $2l_2$ etc., are then given as shown in the diagram. This procedure can also be adapted for other shapes of pulses when the rise of pressure in the front is very steep (1).

3. THE X–T DIAGRAM APPROACH AND THE BASIC THEORY OF ELASTO-PLASTIC WAVE PROPAGATION

A very convenient way of representing graphically the stress pulse propagation in a bar is by the well-known X–T diagram, also known as the "Stereogram." X, the abscissa of the diagram gives distance along the bar and T, the ordinate, gives time. Regions of constant stress and velocity are plotted in this X–T plane. Thus, from this diagram, the state of stress either at a particular time in the whole bar or at any section for different times, can be obtained by taking horizontal or vertical sections. Thus when a stress region reaches the fracture stress in the X–T diagram, it indicates a fracture and consequently a scab. In order to be able to draw such a diagram, for a given bar, we need to know the following:

(*i*) The stress-strain diagram of the material.
(*ii*) The description of the impact. This may be called the initial condition of the stress propagation problem.
(*iii*) The boundary conditions of the bar, for example, fixed or free end.

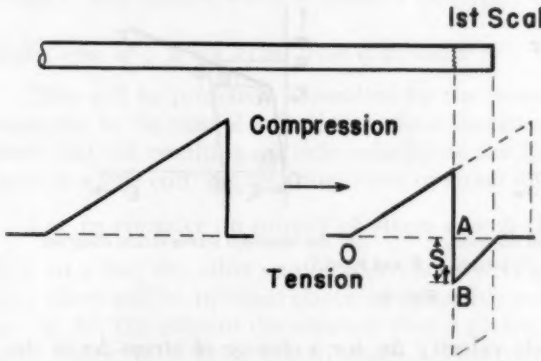


FIG. 1. Stress reversal in a bar with free end due to the reflection of a triangular pulse and the consequent fracture.

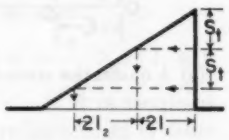


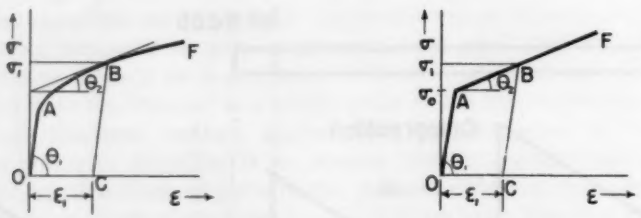
FIG. 2. Simple graphical construction for determining scab lengths l_1 and l_2 from the given shape of a pulse.

Since scabbing occurs when the other end is free, we shall assume this as the boundary condition for (*iii*). Here we wish to study scabbing by making use of the basic theory of elasto-plastic wave propagation in solids and so it might be considered desirable to discuss this theory before trying to solve scabbing problems. The propagation of plastic stresses was first studied by Donnell (3) in 1930. The subject was not given much attention until the Second World War, when an extensive study was made of plastic waves due to a longitudinal impact on a long thin wire independently in the U. S. by Von Kármán and Duwez (4), in U.K. by Taylor (5) and in USSR by Rakhmatulin (6). Further work

both experimental and theoretical was carried out by several workers, some of the main ones being White (**7, 8**) and Griffis (**7**), Clark (**9, 10**) and Duwez (**9**), Rakhmatulin (**6, 11**), DeJuhasz (**17**), Lee (**12, 13**), Malvern (**14**), Kolsky (**15**), Rinehart and Pearson (**16**). Because of the nature of the problem, most of the theoretical work done has been semi-analytical and graphical with some simplifying assumptions.

As was indicated above, for drawing an X-T diagram, we need to know the velocity of propagation of the waves and the particle velocity corresponding to any given stress. For elastic wave propagation, these quantities are easily determined and have been known for about a century but for plastic waves, the solution of the partial differential equation of motion involved was obtained only about 15 years ago during the Second World War (**4, 5, 6**).

The velocity of elastic wave propagation is given by $c_0 = \sqrt{E/\rho}$. It can be intuitively guessed and can be easily proved that for a wave of loading with plastic stress σ_1, the velocity of propagation is $c = \sqrt{S/\rho}$ where S is the slope of the stress-strain curve at stress σ_1.



(*a*) A qualitative stress-strain diagram. (*b*) An idealized stress-strain diagram. ($\tan\theta_1 = E$, $\tan\theta_2 = S$)

FIG. 3.

The change in particle velocity Δv, for a change of stress $\Delta\sigma$ in the case of an elastic wave is given by

$$\Delta v = \frac{\Delta\sigma}{\rho c_0} = \Delta\sigma\sqrt{\frac{E}{\rho}}. \tag{1}$$

For a plastic wave with stress σ_1 and strain ϵ_1 the particle velocity is (**4**)

$$v_1 = \int_0^{\epsilon_1} \sqrt{\frac{S}{\rho}}\, d\epsilon. \tag{2}$$

It may be noted that the aforesaid expressions for velocity of propagation and particle velocity hold for a material with stress-strain relation like one shown in Fig. 3. It is assumed that the curve does not have any dip at the yield point, creating what are known as the upper and

lower yield points. σ_0 is the yield stress and E, S the slopes in the elastic and plastic regions, respectively. If the material is loaded up to B, it is a fair approximation to assume unloading along line BC of slope E. On loading again, it follows the path CBF.

In order to exemplify the general procedure of attack on the problem, we shall simplify the stress-strain relations as shown in Fig. 3*b* so that the velocity of propagation of all plastic stresses becomes a constant $c = \sqrt{S/\rho}$.

The particle velocity, however, still depends on the stress level reached and is easily obtained by evaluating the integral (2) as

$$v_1 = \frac{\sigma_0}{\rho c_0} + \frac{\sigma_1 - \sigma_0}{\rho c}. \tag{3}$$

Now, having known the velocities of propagation and the particle velocities for a given stress-strain relation like that in Fig. 3*b* we can proceed to plot the X–T diagram for elasto-plastic stress wave propagation. However, we still have to see how a wave front (or stress discontinuity) will behave when it meets a boundary or another wave front.

Reflections of a Wave Front from a Boundary

This will be primarily controlled by the boundary conditions. For example, in the case of a fixed end, the reflected wave or waves must be such that the resulting particle velocity at the fixed end is zero. Similarly at a free end, the resulting force or stress must be zero.

Let us consider an impact of stress σ such that $\bar{\sigma} = \dfrac{\sigma}{\sigma_0} > 1/2$, say $2/3$, on a bar, the other end of which is fixed (Fig. 4). If it is assumed that there will be an equal elastic compressive pulse reflected, as is done in Fig. 4*b*, the evident discrepancy that a plastic stress of $1\frac{1}{3}$ travelling with elastic velocity c_0 is introduced. To avoid this, we must have a plastic wave front reflected from the fixed end (Fig. 4*a*). Also, before the material becomes plastic, it must yield and so, a wave front of yielding travelling with elastic velocity will proceed ahead of the plastic wave front. Between this wave front and the plastic wave front the material is all at plastic stress (Fig. 4*a*).

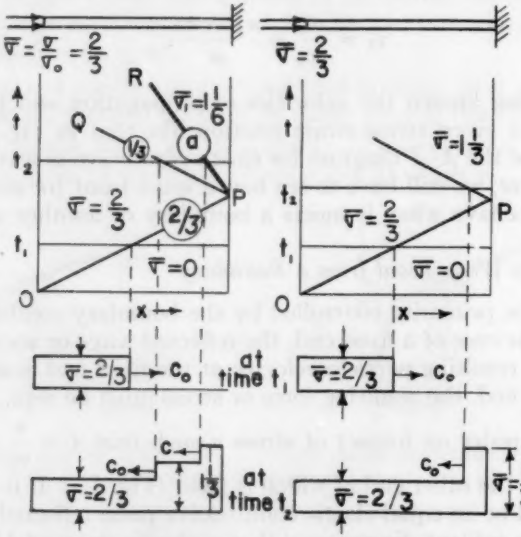
The stress $\bar{\sigma}_1$ in the plastic wave is determined by using the boundary condition that the end of the bar is fixed and so the velocity there must be zero. Velocity at P (Fig. 4*a*) is obtained as a sum of the contributions due to OP, PQ and PR.

$$\begin{aligned} v &= \Delta v_{OP} + \Delta v_{PQ} + \Delta v_{PR} \\ &= \underset{\longrightarrow}{\frac{\Delta\sigma_{OP}}{\rho c_0}} + \underset{\longleftarrow}{\frac{\Delta\sigma_{PQ}}{\rho c_0}} + \underset{\longleftarrow}{\frac{\Delta\sigma_{PR}}{\rho c}}, \end{aligned} \tag{4}$$

where $\Delta\sigma$ denotes the stress discontinuities across the various lines OP, PQ, and PR, and the underlying arrows indicate the direction of the velocity. The values of the stress discontinuities across the various lines are shown enclosed by circles in Fig. 4*a*. Substituting these in Eq. 4 and equating it to zero, we have

$$\tfrac{2}{3} - \tfrac{1}{3} - a \cdot \frac{c_0}{c} = 0, \quad \text{or} \quad a = \tfrac{1}{3}\frac{c}{c_0}.$$

If $\frac{c_0}{c} = 2$, $a = \frac{1}{6}$ and $\bar{\sigma}_1 = 1\frac{1}{6}$.



(*a*) Reflection of an elastic wave front from a fixed end, resulting into elastic and plastic wave fronts and region of yielding in between.

(*b*) Assumed elastic reflection of an elastic front, showing the fallacy of a plastic stress travelling with elastic velocity c_0, which is impossible.

FIG. 4. Reflection from a fixed-end boundary.

If the other end of the bar is free, the boundary condition of zero stress has to be satisfied so that the reflected stress wave must be a tensile stress wave of $\bar{\sigma} = \frac{2}{3}$ and no plastic stress will be created.

If instead of a weak impact which creates elastic stresses, a strong impact is given, both elastic and plastic stresses and stress discontinuities will be generated (Fig. 5). This must be so because before the material becomes plastic it must yield and consequently an elastic wave front of yielding with $\bar{\sigma} = 1$ must proceed ahead of the plastic front with $\bar{\sigma} = 2$.

Interaction of Two Stress Discontinuities

Having discussed the reflections of wave fronts and end conditions, let us see how two wave fronts will interact on meeting one another. In fact, after interaction there may result two or three wave fronts, some elastic and some plastic, depending on directions and intensity. Starting with a certain assumed wave pattern, the values of the stress jumps across the postulated wave fronts are calculated (the method of

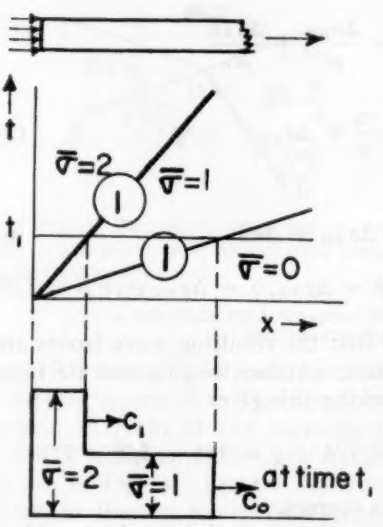


FIG. 5. The X–T diagram for the propagation of an elasto-plastic stress state starting from the impacted end.

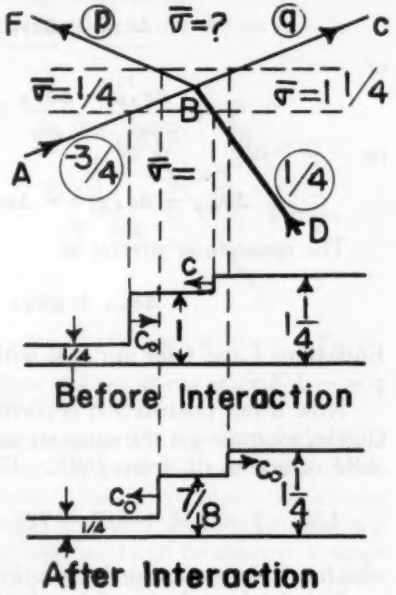


FIG. 6. Interaction of a compressive elastic and tensile plastic wave front, resulting in two elastic wave fronts.

calculation will be discussed below) and checked for compatibility with the stress values around them. Usually, only very few possibilities need to be tried to obtain a compatible set.

To make the procedure explicit and more clear, we shall consider two examples of some distinctly different cases.

(*a*) Let $c_0/c = 4$

In Fig. 6, AB and BD are two elastic and plastic stress discontinuities travelling in the X–T plane. At B they interact. AB being negative and BD positive, they will cancel one another to a certain extent and so we may assume that the resulting wave fronts will be both elastic (Fig. 6). Let p and q be the stress jumps across BF and BC,

respectively. To determine these two unknowns, we make use of the fact that in region *FBC* there is *uniform stress and velocity*. Hence the stress and velocity calculated as a superposition of the stress discontinuities to the left of *B* must be equal to the stress and velocity to the right of *B* from *BD* and *BC*. This gives two equations in p and q enabling their determination.

The *equation of velocities* is

$$\Delta v_{AB}^{\rightarrow} + \Delta v_{FB}^{\leftarrow} = \Delta v_{BD}^{\leftarrow} + \Delta v_{BC}^{\rightarrow}$$

or

$$\frac{\Delta\sigma_{AB}}{\rho c_0} - \frac{\Delta\sigma_{FB}}{\rho c_0} = -\frac{\Delta\sigma_{BD}}{\rho c} + \frac{\Delta\sigma_{BC}}{\rho c_0}$$

or

$$\Delta\sigma_{AB} - \Delta\sigma_{FB} = -\Delta\sigma_{BD}\cdot\frac{c_0}{c} + \Delta\sigma_{BC} \tag{5}$$

The *equation of stresses* is

$$\Delta\sigma_{AB} + \Delta\sigma_{FB} = \Delta\sigma_{BD} + \Delta\sigma_{BC}. \tag{6}$$

Equations 5 and 6 for our case with $p = \Delta\sigma_{FB}$, $q = \Delta\sigma_{BC}$ give $p = 5/8$, $q = -3/8$.

Now if our postulation is correct that the resulting wave fronts are elastic, we must get the same stress state, whether we go across *BF* from *ABF* or across *BC* from *DBC*. Checking this gives

$$1/4 + p = 1/4 + 5/8 = 7/8 \text{ and } 5/4 + q = 5/4 - 3/8 = 7/8$$

which are the same, so the solution is correct.

This is the only possible solution to the above interaction problem because of the known uniqueness of such wave solutions.

(*b*) Let $c_0/c = 2$

In Fig. 7, we again face a situation similar to the previous one. Again assuming that elsatic wave fronts result after interaction, let also $c_0/c = 2$.

The *equation of velocity* is $-1/4 - a = b - 2(1/4)$ and the *equation of stresses* is $-1/4 + a = b + 1/4$, so $a = 3/8$, $b = -1/8$.

The *check* equations

$$3/4 + 3/8 = 9/8 \quad \text{and} \quad 5/4 - 1/8 = 9/8 \quad \text{are}$$

satisfied, but the stress $\bar{\sigma} = 9/8$ becomes plastic which is not permissible when the wave fronts surrounding it are travelling with elastic veloci-

ties. Thus, the above postulation is not correct. Since a plastic stress is created, let us assume that the plastic wave front does not die out (Fig. 8). Before the plastic stresses are reached, the material must become yielded and so a wave front of yielding BF of stress jump 1/4 must be present. Also, in order to balance momentum on both sides, we have an elastic wave of unloading BC travelling towards the right. Then the velocity and force equations are $1/4 - 1/4 - 2p = q - 2(1/4)$ and $-1/4 + 1/4 + p = q + 1/4$ so that $p = 1/12$, $q = -1/6$ and $\bar{\sigma} = 13/12$ which can be checked and are compatible.

In this way, most of the interaction problems can be solved.

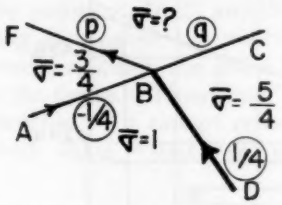


FIG. 7. Postulated interaction of an elastic and plastic wave front of equal stress jumps and opposite sign.

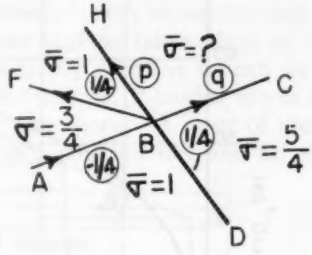


FIG. 8. The corrected picture of Fig. 7.

4. SOLUTION OF A SCABBING PROBLEM IN A BAR BY THE ELASTIC AND ELASTO-PLASTIC APPROACHES

Now we will see some problems of propagation solved by the X–T diagram approach. The first thing that we need to have is the stress-strain diagram of the material chosen. As an example, we choose 14S-T4 aluminum alloy, the stress-strain diagram of which in tension is given in Fig. 9. For the elastic analysis, we have to assume a single straight line up to fracture stress. For the plastic analysis however, the straight two-line relation as shown in Fig. 9 is fitted and it is assumed that the stress-strain relation in compression is similar. For this material, we take

$$\sigma_0 = 41{,}000 \text{ psi.} \tag{7}$$

$$\frac{c_0}{c} = \sqrt{\frac{E}{S}} = \sqrt{\frac{\tan\theta_1}{\tan\theta_2}} = \sqrt{8.95} \simeq 3 \tag{8}$$

$$E = 11 \times 10^6 \text{ psi.}, \quad \rho = 0.101 \text{ lb/in}^3 = 0.00314 \text{ slugs/in}^3$$

$$c_0 = 17100 \text{ ft./sec.}$$

$$\sigma_{\text{fracture}} = 65{,}000 \text{ psi.} \equiv \bar{\sigma} = 1.6. \tag{9}$$

Let us now consider the propagation of a triangular pulse of peak pressure $\bar{\sigma} = 2\frac{1}{8}$ and duration 50μ sec. in a bar. By the completely

elastic analysis, there will be one scab the length of which can be determined as follows:

$$\text{Length of the pulse in the bar} = c_0 \times 50 \times 10^{-6} \text{ ft.} = 10.3 \text{ in.}$$

$$\text{Length of the scab} = \frac{1}{2}\left[\frac{1.6}{2.2} \times 10.3\right] \cong 4 \text{ in.}$$

However, things do not remain the same once we take plasticity into account. Let us consider a triangular pulse of the same shape as above

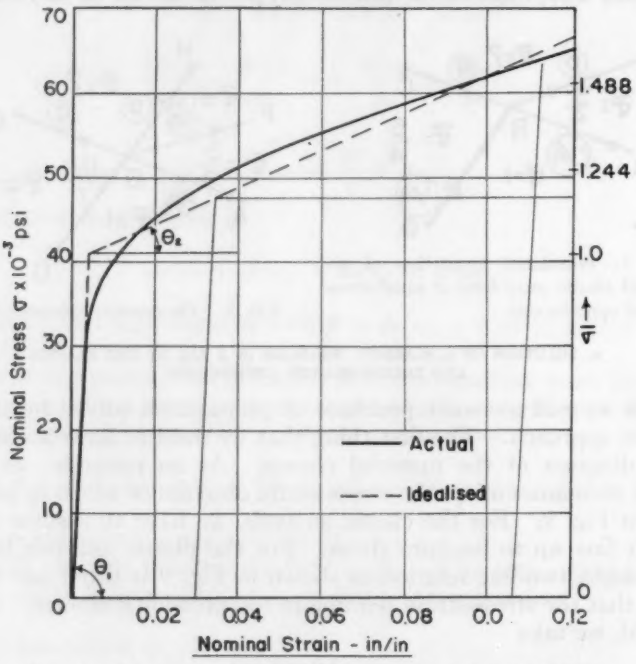


FIG. 9. The actual and idealized stress-strain relations for 14S-T4 aluminum alloy in simple tension.

($\bar{\sigma} \cong 2\frac{1}{2}$). The pulse is broken up into four steps of $\bar{\sigma} = 0.5$ difference in their ordinates. The impact is specified by velocity and so each rectangle corresponds to a certain constant velocity. At O, an elastic and a plastic pulse start. At B, an elastic front of unloading starts and interacts with the plastic front at C. The plastic front becomes weaker ($\bar{\sigma} = 3/4$) and an elastic front is reflected back to D. From D, the front CD should be reflected as if from a fixed end as the impact is still going on, but in addition to the reflected pulse, there is another elastic front of unloading of magnitude $-1/2$. Hence, the resulting front that

starts from D is $-1/2 + 1/4 = -1/4$. In this way, the plastic front continues up to K, beyond which the bar becomes elastic.

One interesting feature occurs when the tensile wave, generated after reflection from the free end, reaches the region of the bar previously left under permanent strain by the incident plastic wave. For convenience in plotting on the X–T diagram (see Fig. 10), the concept of permanent strain waves becomes useful. Plastic wave OC has permanently strained a part of the bar to a plastic strain corresponding to a compressive stress $\bar{\sigma} = 2$. So also waves CF, FH and HK have left residual strains corresponding to $\bar{\sigma} = 1\frac{3}{4}$, $1\frac{5}{8}$ and $1\frac{3}{8}$, respectively. On looking at the loading diagram, Fig. 11, we can see that these four regions correspond to the points F, D, C, and B in compression. On unloading and then loading in tension, the yielding of these regions takes place at varying stresses, which are given by points G, H, J and K as can be read from the figure. Thus when the elastic front M, P having stress jump -1 reaches P, it cannot remain elastic any more. A front of yielding PQ with value -0.62 must go ahead of a plastic front and an elastic

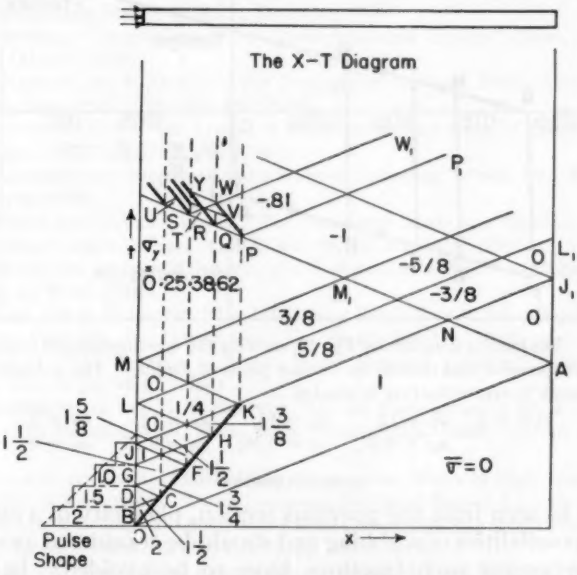


FIG. 10. The elasto-plastic stress wave propagation due to a short-time triangular pulse in a free bar of aluminum 14S-T4.

TABLE FOR STRESS JUMPS IN FIG. 10.

OC	1	FH	5/8	KM	3/8	AP	− 1	QR	−0.38	RS	−0.25
BC	−1/2	FJ	1/8	KN	−3/8	PQ	−0.62	VT	−0.24	WY	−0.14
CD	1/4	GH	−1/2	HL	1/4	PV	−0.19	VW	−0.07	PP_1	−0.19
CF	3/4	HK	3/8	LL_1	−1/4	QT	−0.12	RT	−0.065	WW_1	0.0825
DF	−1/4	JK	9/8	MM_1	−3/8	QV	0.12	RU	−0.065		

front PP_1 is reflected back in the non-plastically strained region. The values of PV and PP_1 have to be determined by the equations of continuity of velocity and forces as discussed before. In this way, plastic waves of tensile stresses are created at P, Q, R, S, etc. Hence, the vertical lines in Fig. 10 can be treated as a separate kind of wave (even though some of their mathematical properties are singular) and might be called *permanent strain waves*. The interactions in the region $PQRS$ are too many and are not completed because the stresses are all decreasing. Consequently, the permanent strains are also not plotted.

In the above solution, it may be noted that the largest tensile stress is -1, which is smaller than the fracture stress -1.6 and so scabbing is not possible. If actually scabbing does occur for the above case, it should be a clear indication that the stress-strain diagram in dynamic loading is much different from that in static loading.

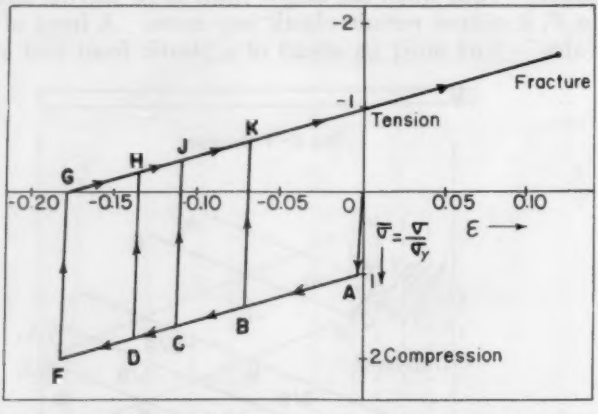


FIG. 11. The loading diagram for Fig. 10, showing the non-dimensional stress-strain relationships in compression and tension for various paths of loading. The unloading wave was not strong enough to create fracture in tension.

$$c_0/c = 3, \quad \sigma_B = 1\tfrac{1}{4}, \quad \sigma_C = 1\tfrac{1}{8}, \quad \sigma_D = 1\tfrac{1}{16}, \quad \sigma_P = 2$$
$$\sigma_K = 0.62, \quad \sigma_J = 0.38, \quad \sigma_H = 0.25, \quad \sigma_G = 0$$

5. CONCLUSIONS

As can be seen from the previous section, plasticity of a material reduces the possibilities of scabbing and should be considered as a desirable property wherever such fractures have to be avoided. In fact, the plastic wave front acts somewhat as a shield in not letting the strong compressive pulse penetrate through and reach the free end. Before these pulses reach the free end, their strength is very much reduced because of their multiple interactions with the plastic front, thus preventing scabbing completely in some cases.

However, it is quite likely, because of the very high rate of loading and the resulting brittle fracture, that the static stress-strain diagram

is not quite applicable. The actual diagram is probably less plastic. The analysis in such a case can be done on lines similar to those carried out in this paper once the dynamic relations are determined, experimentally or otherwise.

In the analysis of scabbing in plates, the state of stress is closer to plane strain rather than plane stress, hence the above approach using the maximum stress fracture criterion would have to be modified accordingly.

Acknowledgment

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Shock-Absorbing Plastic Foam.—A new shock-absorbing plastic foam that is more adoptable for packaging beause it is not "sticky" has been developed for the Air Force. The addition of a fatty acid such as stearic acid, to common foam plastics by Air Research and Development Command scientists eliminated the "stickiness" and produced a more resilient material of variable density.

Known as polyurethane foaming, the process is used to protect equipment during shipping by bedding it in a high-strength, lightweight foamed plastic. The thick protective cushion is either molded individually as a container, or foamed into the container holding the item to be shipped.

Two chemicals, polyester or polyether resin and isocyanate, are poured into the mold or container with an amine catalyst. A chemical reaction takes place releasing carbon dioxide in a thick foam which hardens in a few seconds.

Formerly, it was necessary to wrap equipment in polyethylene or waxed paper to prevent foam from "sticking" to its surface. Molds also required waxing after each molding operation.

The improved plastic using the additive does not adhere to bare metal or glass surfaces.

Use of the additive has also improved static load carrying properties. Under seven-tenths pounds per square inch pressure, foamed plastic cushions, without the additive, showed 80 per cent strain. With the additive, the same pressure revealed only 18 per cent strain. Density of the material may be controlled by varying the quantity of fatty acids.

Scientists from ARDC's Wright Air Development Center, Dayton, Ohio, developed the new polyurethane foaming process with additive in the Protective Processes Materials Laboratory.

"Shirt Button" Electron Tube.—Development of an electron tube not much larger than a shirt button has been announced by the General Electric Research Laboratory. The miniature tube is capable of operating at temperatures of from 900° to 1500° F.

The experimental models now being evaluated, shaped like flat disks, measure only $\frac{1}{4}$ in. in diameter and $\frac{1}{8}$ in. thick. Their extremely small size is due in part to the fact that they contain no heater, all the heat necessary being provided by their environment. The design is still in the laboratory stage and no tubes are commercially available at this time.

The new design is the latest in a series of developments that have brought the electron tube, once bulky and fragile in its glass envelope, down to the size of its competitor, the transistor. At the same time, the ability of the new tubes to withstand high temperatures makes possible extensive weight reductions, since heavy, bulky cooling equipment becomes unnecessary.

In September, 1956, General Electric revealed the development of a variety of electronic components that could operate in the same temperature range as the tube announced today. The new tube is considerably smaller, however, than any shown at that time. Like its predecessors, it is constructed of layers of titanium and a special ceramic.

James E. Beggs, the General Electric scientist credited with being the "father" of much of the Research Laboratory's high-temperature electronics program, pointed out at the time of the earlier announcement that "the performance of high-temperature components we have developed compares favorably with previous devices that would operate only at low temperatures."

RESEARCH—FOUNDATION OF STEEL'S PROGRESS TODAY *

BY

JAMES B. AUSTIN [1]

The invitation from Dr. Burlew to address you this evening is deeply appreciated for several reasons. First, I am immensely pleased that you have established a series of lectures in honor of Bill Coleman whom I knew well and valued as a friend. Second, I am indeed honored at being asked to give the first of these lectures. Yet I am also conscious of the obligation which goes with this honor, because the responsibility of setting a pattern to match Bill's great spirit and human accomplishment is a heavy one.

It is quite unnecessary to say much about Bill Coleman before an audience at The Franklin Institute because many of you knew him as well, or better, than I did. Yet I should like to take this opportunity to acknowledge my indebtedness to him in an area which may not be familiar to you. He and I had a common bond in that each of us had served The American Society for Metals, though our tenure of office was separated by twenty years. Bill was President in 1933 at a very critical time in the Society's history. The depression was making things rough for all technical groups but, in this case, the Society was in the process of being metamorphosed from The American Society for Steel Treating to The American Society for Metals. Bill had much to do with the successful accomplishment of this transition and contributed greatly to putting the new Society on a firm and enduring basis. When I became President in 1953, the wisdom of Bill Coleman and his colleagues was amply clear when viewed in the perspective of the intervening years. Although the problems I faced during my term of office were minor compared to those that Bill wrestled with, I was always grateful for the sound advice which he gave so willingly. Bill was always ready to help and his help was well worth having. And so it is with a sense of gratitude and humility that I am here tonight to inaugurate this series of lectures which you have established to honor the memory of a man who was richly endowed in wisdom and in warmth and who was willing to share them.

Organized industrial research, as we know it today, is a relatively new activity with a history somewhat reminiscent of that of Moses.

* The First William B. Coleman Lecture, delivered at the Annual Meeting of the Institute, January 15, 1958. The Lectures, made possible through a gift from Mr. and Mrs. William B. Coleman, are to be given every other year, preferably in the field of metallurgy.

[1] Vice President, Research and Technology, United States Steel Corporation, Pittsburgh, Pa.

Its date of birth is uncertain but it appeared as a lusty infant in the industrial bulrushes about the beginning of this century. It suffered the usual growing pains and passed through an adolescent period of insecurity to attain a fruitful maturity and to be heralded by many as the guide to the wonderland of tomorrow. If any of you wish to push this analogy to a human being a bit further to say that at the present time there is a danger that future growth may be more in girth rather than in height, I am not disposed to argue the point.

About the turn of the century, a number of industries were venturing to invite scientists to join them in setting up research programs beyond the usual engineering development or "trouble-shooting." One outstanding example, which is appropriate for an audience at The Franklin Institute, is that of Dr. F. B. Jewett, then at Massachusetts Institute of Technology, who was invited by the American Telephone and Telegraph Company to investigate telegraph damage caused by lightning. This led to his being asked to guide a group of scientists in further research on a telephone repeater for use in long distances lines. From this small beginning grew the great Bell Telephone Laboratories of which Dr. Jewett became first president.

At about the same time, other firms were moving in the same direction. The General Electric Company asked Dr. Willis Whitney, also then at MIT, to form a research laboratory for broad investigations in the field of electricity. The E. I. du Pont Company also established a laboratory under the direction of Dr. Charles Reese, and shortly afterwards the Eastman Kodak Company enlarged its experimental laboratory and put Dr. Kenneth Mees in charge. The growth of all these organizations is well known to you.

The influence of science upon the steel industry since the days of William Kelly and Sir Henry Bessemer has not been as well appreciated by the public as has its more spectacular impact upon younger industries. The problems which confronted management in this period were chiefly those of handling material in ever greater quantity. Many of us, I fear, are inclined to underestimate the ingenuity of the engineers who designed, and still design, the massive equipment used in steel mills. The blast furnace, for example, in its mature form is a device which combines metallurgical efficiency with low cost for large scale production, and this very circumstance has discouraged research in ore reduction.

It is interesting, however, that one unit of the steel industry, a unit now part of United States Steel, made one of the significant beginnings in physical metallurgy. In 1891, W. R. Walker at South Works of the Illinois Steel Company, employed the Belgian scientist, Albert Sauveur, to undertake the study of steel with the aid of the microscope. This was indeed a venture on the frontiers of knowledge for it is probable that at this time no one else in this country was able to examine an

opaque metal specimen at moderate magnification. And even in Europe the number was probably limited to three or four. Unfortunately, Sauveur discontinued this connection after a few years but he went on to become world famous for the light which his studies were to cast on the behavior of steels.

As industrial research has grown in this country it has varied in emphasis, and in details, but has followed certain general patterns. In fact, the proper kind of a program for a given industry or company can be determined largely on the basis of the following questions:

1. Are the products and manufacturing processes of the company based on recent scientific advances or are they based on a mature technology founded on well-established tradition?
2. Do the company's products go directly to the consuming public or are they basic materials for other manufacturers?
3. Is there a raw material problem with respect to either quantity or quality?

Taking the first question, the electrical and communication companies are good examples of businesses which are presently based on relatively recent scientific advances, such as the vacuum tube and the transistor. This requires that they have active research programs in certain fields of science. The steel industry, on the other hand, is based largely on a mature technology with which we are, in part, only now catching up scientifically. Research in steel has therefore, for some time, concentrated in somewhat different areas. It is our hope, however, that before long we too shall be basing our business on recent advances in science.

With regard to the second question, the steel industry is one which sells a basic material for others rather than a product which goes directly to the consumer. It cannot, therefore, depend on making new gadgets or new drugs to increase its markets. Instead, it must provide new types of material which its customers can convert to items for use by the public. This again dictates certain directions of research.

Finally, as to the third question, the steel industry faces problems in the matter of finding the most economic raw materials which are not faced by the electrical industry, for example, and so it must devote considerable attention to research in this field.

I have spoken thus far only in very general terms about the kinds of research which the steel industry must undertake. To illustrate them more specifically I shall take U. S. Steel's program which has four objectives. They are:

1. To make most effective use of its raw materials.
2. To find new or improved processes for the manufacture of quality steel and for making products from it.

3. To develop new and improved products to meet the needs of customers and so to extend and diversify its product line.

4. To acquire new and improved scientific knowledge to sustain healthy technologic growth.

A further aim is to achieve these objectives at lowest cost.

To carry out this program, we have some twelve hundred persons working in four major laboratories. The chief one is our Research Center at Monroeville, Pennsylvania, where almost one thousand are employed in both basic and applied areas. This is the laboratory in which most of the work on coal and coke, steelmaking and coated products is carried out. Another laboratory in Pittsburgh is devoted exclusively to the study of problems associated with the production and use of tubing and pipe. A third, in Cleveland, studies problems arising in the production and use of wire and wire products. The fourth, in Duluth, is concerned with beneficiation and concentration of ores.

But it is our fourth objective, the search for new and improved knowledge, that I wish to emphasize tonight. This is the type of investigation often called basic or fundamental research. A new, and more appropriate, name now being used by many is "learning research." For it is in this field that we learn many things upon which the technology of tomorrow will be based. In other words, it supplies the raw material for applied research. But just exactly what is basic or learning research? And why should industry carry it on?

Basic research is a subject that is easier to talk about than to define, but to avoid confusion I shall attempt to state what I mean by this term. For our purposes today, I believe a reasonably acceptable definition is this: basic research is research without an immediate, commercial objective. The two qualifying adjectives are significant words, because all research has some goal, even if it be only to satisfy the curiosity of the investigator.

As to the word "immediate," Professor Glenn Seaborg has pointed out that the essential difference between basic and applied research is in the time scale for utilization of the results. Applied research is aimed at application, or commercial use, in the immediate future. On the other hand, the sights of basic research are fixed on a more distant date, in rare instances even approaching infinity, though one can never tell when the results of even the most abstract research will prove helpful. For example, I am certain that the mathematicians who worked on non-Euclidian geometries in the latter part of the 19th century did not expect their results ever to be put to use, yet they are decidedly useful in mid-twentieth century physics.

The other objective, "commercial," is likewise significant because even in basic research one can have an immediate objective of some urgency. For example, it may be imperative to get an immediate ex-

perimental check on some new theory. As a specific illustration, there is the recently widely publicized check of the suggestion that the principle of parity, a foundation stone of nuclear physics for many years, is in fact not valid.

If at times, tonight, I seem to get rather philosophical about basic research, it is because one of the greatest contributions of such research is to natural philosophy. The most significant, and most enduring, results are usually those which arrive at some new concept or permit the generalization of much information by a brief statement in the very concise language of mathematics. For instance, a basic study of the mode of transformation of steels at constant temperature, begun 30 years ago in our laboratory, has produced a great body of data on the behavior of individual steels. This information is useful in certain heat treating operations—but its greatest value is that it led to a new concept of the function of alloying elements in steel.

Now that we have defined our terms, we can consider a question which is frequently raised. Why do basic research in industry? Is not this traditionally the province of the university? Certainly this has been true in the past and I suspect that primary responsibility for such research will continue to belong to the academic laboratory. But the accumulation and organization of knowledge has become such an important national resource that we can no longer afford to leave it entirely to the random curiosity of the academic investigator. For without new or improved knowledge to nourish it, applied research cannot flourish. To support the enormous amount of industrial and military development now going on, we need an ever expanding store of basic knowledge. Yet the academic world, both in this country and elsewhere, is finding it increasingly difficult to carry on its traditional function, particularly in the face of very strong temptations to engage in applied research itself.

To be a bit more quantitative about it, it is estimated that the total amount spent in 1956 by industry, government, universities and nonprofit research institutions on research and development was of the order of seven billion dollars. This is nearly 25 per cent more than in 1955, and 58 per cent over 1953. Of this amount something between 5 and 10 per cent appears to have gone to gaining a deeper understanding of natural phenomena—in short, toward basic research. In view of the rapid growth of the total research effort, this is not enough. More consideration must be given to maintaining the supply of seed corn. So it seems to me that the real question is not: should industry do basic research, but rather, can industry afford not to enter this field.

Granted industry's need for more basic research, there is the corollary question: should industry set up its own laboratories or support such work at a university? The answer is clearly, both. By supporting academic research one can often acquire, for a temporary need,

some special knowledge or skill, or the use of some special piece of equipment. Moreover, the academic laboratory is the training ground for the scientific and technical manpower of which industry is in great need. By supporting the university laboratories one is not only contributing to the advancement of knowledge but is aiding in the development of an important human resource.

But there is a danger here. Industry must be careful not to try to warp university research too much along the lines of its own specific interests. Otherwise, it risks losing many of the extra and unanticipated dividends which from time to time come out of academic research. It is somewhat safer to support a group whose natural interests coincide with your own, or to put your money on an imaginative and productive investigator. Best of all, perhaps, is to leave your support unrestricted.

On the other hand industry should, in my opinion, itself engage in basic research—for several reasons. The most obvious one is that industry can thus help directly to increase the supply of basic knowledge, particularly to its own applied research. For another, industry cannot always count on finding an academic investigator whose interests parallel its own. As an example, our own laboratory some years ago undertook a fundamental study of factors influencing the thermal expansion of aggregates of refractory oxides, largely because there was difficulty in getting it done elsewhere.

A third reason for industry to engage in basic research is that it needs on its own team men trained in scientific disciplines, and conversant with current trends, to aid in its planning and to recognize in terms of the company's interest the significance of recent advances in many fields of science. This point was discussed at some length recently by Dr. Alan Waterman of the National Science Foundation, who stressed the fact that careful attention to the findings of basic research can often sway a decision for, or against, a particular development, thus saving money and effort.

In a somewhat similar vein, Dr. Guy Suits of the General Electric Company has given three specific examples of ways in which basic research can provide information of great value in arriving at a decision on profitable directions for further study. The first deals with steels for use in electrical machinery—the so-called magnetic steels. These are being constantly improved in many ways, but with respect to one important property—magnetic saturation—a point of diminishing returns appears to have been reached. Fundamental understanding of magnetism is well advanced so that the source of the magnetic flux saturation can be identified in the alignment of the spins of the electrons within the atoms of each element. As it is difficult at present to conceive how such a basic property of an atom can be altered, we appear to be facing a limit, and one which is closely approached by the best soft magnetic materials now available. He, therefore, points out that in

this case, basic research has found a natural limit which technology has now substantially achieved.

As a second example, he cites the recent demonstration that a perfect crystal of iron in the form of a tiny filament has a tensile strength of the order of two million pounds per square inch, which is much greater than that of any massive metal or alloy. Thus, we have a natural limit which current technology has not even approached.

His third example is nuclear fusion which, hopefully, can someday be adapted to the production of power. None of the limits of temperature, pressure, reaction rate, efficiency or other important characteristics of this process are now known. So we have here a case in which the limits imposed by Nature are still largely unknown and the technology does not exist. This is the sort of guidance which basic research can give.

Finally, basic research can be extremely useful in providing new and improved tools for research, or for other parts of a business. A good example is communication theory which is proving valuable in many ways.

Thus far, I have considered the relative advantages of doing basic research in an industrial laboratory as contrasted with supporting it in a university. It is probably quite unnecessary for me to point out to this audience that these are not the only alternatives. For there are a number of research institutes which carry on research, including basic research, either under contract or on their own. Among the outstanding examples are the laboratories of The Franklin Institute, Battelle Institute in Columbus and Mellon Institute in Pittsburgh. Such institutes can well be utilized in the over-all research effort. Or one can team up with other interested firms in a joint research program, as for instance, the work sponsored by the American Iron and Steel Institute which may be carried out either in a university or in a research institute.

To illustrate the nature and scope of our Applied Research program, I shall cover very briefly a few typical projects. Under our first objective, to make the most effective use of our raw materials, we have extensive activity in both ore and coal.

In addition to searching for iron ores in foreign countries, we have an active program on beneficiation and concentration of lean ores in this country. We are also studying intensively the various coals available to us to see how they may be treated, or blended, to give improved coke quality.

Although not strictly in the field of raw materials, I should mention here an active program in coal chemicals, since we are a large producer of these materials. We are interested in producing a number of products using raw chemicals from coal as the base. For example, we have several programs on improving creosote products and extending their

use. One of these gets us into the biological field in the preservation of wood.

Under the objective of new processes we have many different approaches. An experimental blast furnace offers the possibility of testing various types of burden to see which the blast furnace likes best. Among the materials of current interest is sinter and this can be studied in our pilot sinter plant at our Research Center at Monroeville.

Likewise we are seeking ways to improve the production of the open-hearth. One feature of special interest is combustion and for this purpose we have a small $\frac{1}{12}$ scale model at our steelmaking laboratory in the Chicago district.

We are, of course, much interested in unconventional processes such as direct reduction. We are currently studying a fluidized-bed process for reducing iron ore into hydrogen. This process seems to be technically feasible but its economic advantage is still uncertain.

Similarly, a research program on the reduction of hydrogen in steel to be used for large forgings has resulted in the commercial production of vacuum cast ingots.

In the line of new and improved products, we are continuing the improvement of electrolytic tin plate. We have also developed a steel coated with vinyl plastic which has many uses. Enameled sheets are also receiving attention as they are an excellent material for new curtain wall construction.

In railroad materials, we are studying the behavior of car wheels using a special dynamometer which enables us to simulate the effect of braking a 100-car train going at 90 miles an hour.

We are developing new alloy and stainless steels for use by the aircraft industry. Of particular interest is a new method of rolling called "sandwich" rolling which enables us to produce large sheets of materials which are otherwise difficult to roll.

This thumbnail sketch is not very informative except as it illustrates the diversity of our investigations.

As I mentioned earlier, in the field of new knowledge, the greatest and most enduring contributions are usually those which contribute to an understanding of some broad phenomena or which enable one to generalize a mass of data into some concise mature material form. Our early work on isothermal transformation was an example of this. Other illustrations are Dr. Darken's work on 3-phase equilibria and his operational treatment of the Kirkendall effect in diffusion. In a slightly different area, Mr. Larsen's recent book on the theory of the open-hearth attempts to draw a general over-all philosophy for this process.

With the ever growing application of physical chemistry and especially thermodynamics to metallurgy, it is essential that we have a larger body of precise basic data in a number of areas. For example, we are making measurements of the thermodynamic activity of carbon in vari-

ous iron-alloys systems and are making measurements of the diffusivity of carbon in a number of them. Strange as it may seem at this late date, there are still some unanswered questions on some important phase diagrams. Even the iron-carbon system needs further detailed study. Also of current interest is the iron-aluminum-nitrogen system, and in particular the solubility product of aluminum-nitrogen and other nitrides.

In a totally different field, related to process metallurgy, we are investigating, in a basic way, the behavior of a column packed with granular solids when gas rises counter-current wise. This is a problem of general interest to the chemical industry but has a special significance for us since the blast furnace is such a column.

In classical physical metallurgy there are still many unsolved problems; for example, a detailed knowledge of the relation between microstructure and properties has still not been achieved.

Current research in the field of the solid state has opened fascinating possibilities. What is the ultimate strength of iron and how may we hope to attain it? The strength of fine iron filaments shows us that we have a long way to go and leads us into the fruitful field of vacancies and dislocations. The little atoms that aren't there have become very important and various types of imperfections are becoming of ever greater interest. What is the effect of dislocations on diffusion? What is the reaction between imperfections and impurities such as nitrogen or hydrogen? Again we know little about creep. What is it? How is it affected by lattice imperfections, by environment, or by cyclic loading or variation in temperature? There are also great unexplored areas in the surface chemistry of solids and in magnetism. All of these frontier areas must be investigated.

A little earlier in these remarks I attempted to distinguish between basic and applied research. This was convenient for the purposes of discussion and such a distinction is sometimes made physically in order to insure that some part of the research staff is not overwhelmed by the pressures of short-range problems of great urgency. In closing, however, I should like to take somewhat the opposite view. Basic research in industry can properly be evaluated only in terms of the over-all research and development effort. It is an essential part of the whole research team and its activities must be properly coordinated and integrated in the total program. For there should be, and usually is, a feedback from applied research and development into basic research.

An amusing and historically somewhat extended illustration is the growth of the mathematics of probability. It all started in the late Renaissance with the highly practical objective of helping gamblers to win. This was certainly the aim of Cardan and the other early investigators. Later the subject was extended by a number of mathematicians whose chief interest was intellectual satisfaction. In the 20th

century, we have swung full circle and the mathematics of probability is being applied in all manner of industrially useful ways, such as quality control and the design of experiments. And now the mathematicians are busy making still further extensions—but at a faster tempo. We shall not have to wait several centuries for completion of the next cycle. Rather, there is now a constant synergic effort which is spurring both basic and applied research. This is truly a case in which the whole is greater than the sum of its parts.

And all this leads me to the following conclusion which I think Bill Coleman would share with me:

> "The rapid progress true Science now makes occasions my regretting sometimes that I was born too soon. It is impossible to imagine the height to which may be carried, in a thousand years, the power of man over matter . . ."

So far as I am concerned, this is as apt today as it was when Benjamin Franklin said it almost 177 years ago.

Dr. James B. Austin, Dr. S. Wyman Rolph (then President of the Institute), and Dr. John S. Burlew, Executive Vice President, chat with Mrs. William B. Coleman at the reception preceding the Annual Meeting, at which Dr. Austin delivered the First William B. Coleman Lecture, in honor of the late Mr. Coleman.

FUNCTIONAL CHARACTERISTICS OF A NODE DETERMINANT

BY

RAYMOND E. BONNER,[1] LESTER H. KOSOWSKY[1]
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SYNOPSIS

In most treatments of network theory, the characteristic determinant of a network is expanded by means of the Laplace expansion. Such an expansion always consists of a set of positive and negative terms, and the negative terms always cancel. In this paper a modification of the Laplace expansion is developed which removes initially all of the negative terms and which therefore reduces considerably the labor in making the expansion. The modification will be shown to apply not only to the characteristic determinant but to its first order cofactors as well. In addition a formula will be derived from which the maximum number of terms in the expansion may be computed.

INTRODUCTION

A typical problem in network analysis is to find for a network, such as that shown in Fig. 1, the voltage that is developed from each of the

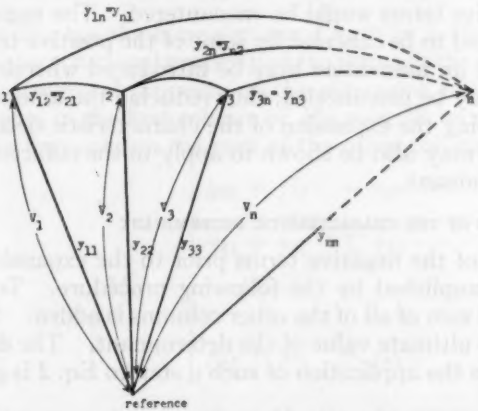

FIG. 1. A general network having n nodes and a reference node.

n-nodes to the reference node in response to a current stimulus that is applied to one or more of the nodes. Such an analysis leads to a set of simultaneous linear equations as follows:

$$\begin{aligned}
&v_1 \sum_{x=1}^{n} y_{1x} - y_{12}v_2 - y_{13}v_3 \quad \cdots - y_{1n}v_n = I_1 \\
&- y_{21}v_1 + v_2 \sum_{x=1}^{n} y_{2x} - y_{23}v_3 \cdots - y_{2n}v_n = I_2 \\
&\qquad \vdots \qquad\qquad\qquad\qquad \vdots \qquad\qquad (1) \\
&- y_{n1}v_1 + - y_{n2}v_2 \cdots\cdots\cdots + v_n \sum_{x=1}^{n} v_{nx} = I_n.
\end{aligned}$$

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In Eqs. 1, y_{ij} represents the branch admittance through which voltage v_j causes current to flow into node i, and y_{ii} represents the admittance of the branch that connects node i to reference.[2] The solution of Eqs. 1 by determinants for the voltages $v_1, v_2, \cdots v_n$ leads to the characteristic determinant Δ which is given in Eq. 2.

$$\Delta = \begin{vmatrix} \sum_{x=1}^{n} y_{1x} & -y_{12} & -y_{13} & \cdots & -y_{1n} \\ -y_{21} & \sum_{x=1}^{n} y_{2x} & -y_{23} & \cdots & -y_{2n} \\ \vdots & & & & \\ -y_{n1} & -y_{n2} & -y_{n3} & \cdots & \sum_{x=1}^{n} y_{nx} \end{vmatrix} . \tag{2}$$

Normally, Eq. 2 would be expanded by the Laplace expansion in which both positive and negative terms would be encountered. The negative terms would then be found to be canceled by some of the positive terms. It is at this point where an innovation may be introduced whereby all of the negative terms may be precanceled, thus reducing the amount of work involved in obtaining the expansion of the characteristic determinant. This innovation may also be shown to apply to the cofactors of the characteristic determinant.

EXPANSION OF THE CHARACTERISTIC DETERMINANT

The precancellation of the negative terms prior to the expansion of the determinant is accomplished by the following procedure. To the first column of Eq. 2 the sum of all of the other columns is added. Such a step does not alter the ultimate value of the determinant. The determinant that results from the application of such a step to Eq. 2 is given by Eq. 3.

$$\Delta = \begin{vmatrix} y_{11} & -y_{12} & -y_{13} & \cdots & -y_{1n} \\ y_{22} & \sum_{x=1}^{n} y_{2x} & -y_{23} & \cdots & -y_{2n} \\ y_{33} & -y_{32} & \sum_{x=1}^{n} y_{3x} & \cdots & -y_{3n} \\ \vdots & & & & \\ y_{nn} & -y_{n2} & -y_{n3} & \cdots & \sum_{n=1}^{x} y_{nx} \end{vmatrix} . \tag{3}$$

[2] The method used in this paper is readily extendable to networks that contain non-reciprocal coupling elements.

Equation 3 may now be expanded by means of the Laplace expansion. In the following expansion of Eq. 3, M_{r1} represents the minor of Δ that is formed by striking out its rth row and 1st column.

$$\Delta = y_{11}M_{11} - y_{22}M_{21} + y_{33}M_{31} - \cdots + (-1)^{n-1} y_{nn}M_{n1}. \tag{4}$$

The symmetric minor M_{11} may be expressed as follows:

$$M_{11} = \begin{vmatrix} \sum_{x=1}^{n} y_{2x} & -y_{23} & \cdots & -y_{2n} \\ -y_{32} & \sum_{x=1}^{n} y_{3x} & \cdots & -y_{3n} \\ \vdots & \vdots & & \vdots \\ -y_{n2} & -y_{n3} & \cdots & \sum_{x=1}^{n} y_{nn} \end{vmatrix}. \tag{5}$$

Since M_{11} has the same structural form as Δ, the assertion may be made that any structural property of the terms in the expansion of Δ must also be a structural property of the expansion of M_{11}. For example, the elements in the first column of M_{11} may all be made positive by adding to the first column the sum of the other columns. This yields:

$$M_{11} = \begin{vmatrix} y_{21} + y_{22} & -y_{23} & \cdots & -y_{2n} \\ y_{31} + y_{33} & \sum_{x=1}^{n} y_{3x} & \cdots & -y_{3n} \\ \vdots & \vdots & & \vdots \\ y_{n1} + y_{nn} & -y_{n3} & & \sum_{x=1}^{n} y_{nx} \end{vmatrix}. \tag{6}$$

The unsymmetric minor M_{r1} may be expressed as follows:

$$M_{r1} = \begin{vmatrix} \sum_{x=1}^{n} y_{1x} & -y_{12} & \cdots & -y_{1,r-1} & -y_{1r} & \cdots & -y_{1n} \\ -y_{21} & \sum_{x=1}^{n} y_{2x} & \cdots & -y_{2,r-1} & -y_{2r} & \cdots & -y_{2n} \\ \vdots & \vdots & & \vdots & & & \vdots \\ -y_{r-1,1} & -y_{r-1,2} & \cdots & \sum_{x=1}^{n} y_{r-1,x} & -y_{r-1,r} & \cdots & -y_{r-1,n} \\ -y_{r1} & -y_{r2} & \cdots & -y_{r,r-1} & \sum_{x=1}^{n} y_{rx} & \cdots & -y_{rn} \\ \vdots & \vdots & & \vdots & & & \vdots \\ -y_{n1} & -y_{n2} & \cdots & -y_{n,r-1} & -y_{nr} & \cdots & \sum_{x=1}^{n} y_{nx} \end{vmatrix}. \tag{7}$$

It may be noted from Eq. 7 that the column bearing the rth column subscript is the only one that does not contain a summation. Therefore by a process of shifting rows and columns, all summations in Eq. 7 may be shifted to positions on the principal diagonal of the minor. Also the column that contains no summation may be shifted to the first column of the minor. Through such a process Eq. 7 may be converted into a form similar to that of Eq. 3. To accomplish the conversion, interchange the second row with the third. Then interchange the resulting third row with the fourth, etc. until the rows bearing row subscripts $3,4,\cdots (r-1)$ have all been elevated one row and the row bearing row subscript 2 is in the position that was originally occupied by the row carrying the $(r-1)$ row subscript. In the determinant so obtained, the column carrying colum subscript r is then interchanged with that column carrying column subscript 2. In making these transformations, a total of $(r-3)$ row interchanges and one column interchange were performed. Thus the algebraic sign[2] of the resulting determinant must be $(-1)^{r-2}$. The elements in the first column of the resulting determinant, since they were obtained from the column bearing the column subscript r in Eq. 7, all carry a negative sign. By writing the algebraic sign of the minor as $(-1)^{r-1}$ and by taking a -1 into the derived determinant, the sign of all elements in the first column may be changed to positive. Thus by the foregoing steps Eq. 7 may be converted into the following equation.

$$M_{r1} = (-1)^{r-1} \begin{vmatrix} y_{1r} & -y_{13} & \cdots & -y_{1,r-1} & -y_{12} & -y_{1,r+1} & \cdots & -y_{1n} \\ y_{2r} & \sum_{s=1}^{n} y_{2s} & \cdots & -y_{2,r-1} & -y_{22} & -y_{2,r+1} & \cdots & -y_{2n} \\ \vdots & & & & & & & \vdots \\ y_{r-1,r} & -y_{r-1,3} & \cdots & \sum_{s=1}^{n} y_{r-1,s} & -y_{r-1,2} & -y_{r-1,r+1} & \cdots & -y_{r-1,n} \\ y_{2,r} & -y_{23} & \cdots & -y_{2,r-1} & \sum_{s=1}^{n} y_{2s} & -y_{2,r+1} & \cdots & -y_{2,n} \\ y_{r+1,r} & -y_{r+1,3} & \cdots & -y_{r+1,r-1} & -y_{r+1,r} & \sum_{s=1}^{n} y_{r+1,s} & \cdots & -y_{r+1,n} \\ \vdots & & & & & & & \vdots \\ y_{nr} & -y_{n,3} & \cdots & -y_{n,r-1} & -y_{n,r} & -y_{n,r+1} & \cdots & \sum_{s=1}^{n} y_{ns} \end{vmatrix} . \quad (8)$$

At this point, it was convenient to define a minor M_{r1}' by the following equation.

$$M_{r1} = (-1)^{r-1} M_{r1}'. \quad (9)$$

Thus M_{r1}' represents the determinant factor in Eq. 8. The substitution

[2] Whenever a pair of rows or columns in a determinant are interchanged, the algebraic sign of the determinant must be changed.

of Eq. 8 into Eq. 4 yields the following expression for the expansion of the determinant Δ.

$$\Delta = y_{11}M_{11} + y_{22}M_{21}' + y_{33}M_{31}' + \cdots + y_{nn}M_{n1}'. \tag{10}$$

The expansion of the characteristic determinant as shown by Eq. 10 consists of a sum of terms in which all of the first order minors have a structural form that is similar to that of Δ. Therefore each of these first order minors may be further expanded into an equation that is similar to Eq. 10 and in which the sum of terms so obtained involves second order minors of Δ. The process may be repeated until all minors have been reduced to yield determinants of the second order. All terms so obtained by repeating the expansion process that is used to obtain Eq. 10 must carry a positive algebraic sign.

From the manner of the derivation of M_{r1} as given in Eq. 8, the only types of second order determinants that are obtained by repeated expansion of any of the minors in Eq. 10 may be shown to be given by Eqs. 11 and 12.

$$\begin{vmatrix} y_{st} & -y_{su} \\ y_{ut} & \sum_{x=1}^{n} y_{ux} \end{vmatrix} = y_{st}\sum_{x=1}^{n} y_{ux} + y_{ut}y_{su} \tag{11}$$

Typical second order determinants

$$\begin{vmatrix} \sum_{x=1}^{n} y_{ux} & -y_{su} \\ -y_{us} & \sum_{x=1}^{n} y_{ux} \end{vmatrix} = \begin{vmatrix} \sum_{x=1}^{n} y_{ux} & -y_{su} \\ x\neq u & \\ \sum_{x=1}^{n} y_{ux} & \sum_{x=1}^{n} y_{ux} \\ x\neq s & \end{vmatrix} = \left(\sum_{\substack{x=1 \\ x\neq u}}^{n} y_{ux}\right)\left(\sum_{x=1}^{n} y_{ox}\right) + y_{su}\sum_{\substack{x=1 \\ x\neq s}}^{n} y_{ux}. \tag{12}$$

In order to show that these determinants are obtained by repeated expansion of a minor in Eq. 11, strike out from Δ its first column and some desired row. Then rearrange the rows and columns to yield the form as given in Eq. 8. From the rearranged determinant, again strike out the first column and some row. Repeat the rearranging. Continued repetition of the process will ultimately yield a determinant of the form given in Eq. 11 or Eq. 12.

The expansion of the determinant in Eq. 11 is straightforward while the expansion of the determinant in Eq. 12 involves the intermediate step of adding its second column to its first. The expansions of both determinants as may be seen from Eqs. 11 and 12 consist of positive terms only. Therefore, the expansion of Δ that is given in Eq. 10 consists of positive terms only. Since the value of a determinant is independent of the method that is employed for its expansion, the proof has been established for the assertion that the expansion of a determinant of the type of Eq. 2 consists of a sum of positive terms only. Therefore

the foregoing method for the determination of the value of such a determinant must cancel, prior to expansion, all of the negative terms which otherwise would be encountered in the straightforward Laplace expansion.

In performing the expansion by the foregoing methods, some labor is involved in the rearranging of the rows and columns within any given minor. The rearranged minor m_{r1} as given in Eq. 8 is expanded around its first column. A comparison of M_{r1} before rearrangement, which is given in Eq. 7, with the rearranged form in Eq. 8 suggests that the labor in rearrangement may be avoided if M_{r1} as given in Eq. 7 is expanded along the column that bears the rth column subscript. The minors which are encountered in such an expansion must then contain the same elements as are obtained from the expansion of the first column of the rearranged minor. They may, however, be in different arrangements. Since each of the minors so obtained may be rearranged to yield the form of Eq. 8, it follows that the expansion obtained by the alternate method, which does not involve rearrangement of rows and columns, must still contain positive terms and the virtue of precancellation of all negative terms is retained.

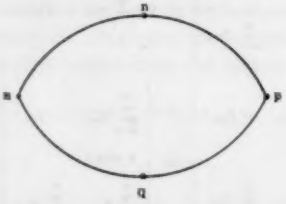

FIG. 2. A closed loop that connects nodes m, n, p and q.

GEOMETRICAL ASPECTS OF THE EXPANSION OF Δ

The terms in the expansion of the network determinant may all be shown to represent trees formed from branches in the network. In order to show this, suppose that some term in the expansion has among its factors the admittances of branches that connect nodes m, n, p, and q into a closed loop as shown in Fig. 2. Since such a configuration is not a tree, it must be established that closed loops cannot be represented by the admittance factors of any term that is contained in the expansion. In order to prove that such a closed loop is an impossibility, let the nodes m, n, p, and q be renumbered from 1 to 4 prior to the writing of the network equations. The characteristic determinant of the renumbered network is given by the following equation.

$$\Delta = \begin{vmatrix} \Sigma y_{1x} & \boxed{-y_{12}} & -y_{13} & -y_{14} & \cdots \\ -y_{21} & \Sigma y_{2x} & \boxed{-y_{23}} & -y_{24} & \cdots \\ -y_{31} & -y_{32} & \Sigma y_{3x} & \boxed{-y_{34}} & \cdots \\ \boxed{-y_{41}} & -y_{42} & -y_{43} & \Sigma y_{4x} & \cdots \\ \vdots & \vdots & \vdots & \vdots & \end{vmatrix}. \qquad (13)$$

Any term in the expansion of an nth order determinant must consist of the product of n factors which are chosen from the elements of the determinant in such a way that every row and column are represented exactly once in the term. In order for a term to have among its factors the admittances that connect nodes 1 to 4 in a closed loop as in Fig. 2, it must have as factors y_{12}, y_{23}, y_{34}, y_{41}, or y_{21}, y_{32}, y_{43}, y_{14}. If all of the branch admittances are bilateral, the two groups of factors are the same, otherwise they are different. For generality they will be regarded as different. Consider the loop that is represented by the branch admittances y_{12}, y_{23}, y_{34}, y_{41}. Such factors are encountered in the expansion of Δ in terms that arise either from the product of the boxed elements in Eq. 13 or from the product of the elements on the principal diagonal. To establish the nonexistence of such a closed loop in the ultimate expansion of Δ, the term that arises as the product of the boxed elements must be shown to be canceled by the term that arises from the product of the elements on the principal diagonal. Since a pair of terms in the expansion, which are to be shown to cancel, will contain factors in addition to the admittances of the branches that form the closed loop, the additional factors must be mutual to both members of the pair. Since this always occurs, the additional factors may be ignored and attention paid only to the admittances of the branches that form the closed loop.

The term in the expansion that contains the boxed elements in Eq. 13 may be expressed as follows:

$$(-1)^r(-y_{12})(-y_{23})(-y_{34})(-y_{41}). \tag{14}$$

The quantity r is the number of permutations of the admittances that are required to alter the subscript sequence from increasing row order to an increasing column order. In expression (14) such a permutation is accomplished by shifting $(-y_{41})$ from the end to the beginning of the string of factors, and r is therefore three. For a loop containing t branches, the number of permutations would be $(t-1)$. If the minus sign in each factor is factored out, the sign of such a term could then be expressed as follows:

$$(-1)^{t-1}(-1)^t y_{12}y_{23}\cdots y_{t1} = (-1)^{2t-1}y_{12}y_{23}\cdots y_{t1}. \tag{15}$$

Since $(2t-1)$ is always an odd number, the algebraic sign associated with a closed loop that is obtained from the product of elements off of the principal diagonal such as the boxed elements in Eq. 13 is always negative. The same term obtained from the product of elements on the principal diagonal always carries a positive sign. Therefore such a pair of terms always cancel. Since the foregoing process may be applied to any closed loop, the conclusion is established that no closed loop may be represented by any term in the ultimate expansion of a determinant of the form of Eq. 2. Since in each term of the expansion of a determinant,

every row and column of the determinant must be represented once, the corresponding geometric representation of a term have must at least one branch connected to every node. Furthermore, since any given term in the expansion of an nth order determinant has exactly n factors, the configuration formed by the branches in any term of the expansion of a determinant of the type of Eq. 2 must be a tree of the network. Thus it follows that if a network is not too complicated, the expansion of its determinant may be obtained by ascertaining by inspection of the network all possible trees that have n branches (1,2).[4]

MAXIMUM NUMBER OF TERMS OBTAINED IN THE EXPANSION OF Δ

With the use of mathematical induction, the maximum number of terms to be obtained in the expansion of Eq. 2 may readily be computed. Consider first a second order determinant of the form of Eq. 11, which may be seen to contain $(n + 1)$ terms. A third order determinant of similar structural form, which is given in Eq. 16, may be shown by expansion to contain $(n + 1)^2$ terms.

$$\text{Third order determinant} = \begin{vmatrix} y_{11} & -y_{12} & -y_{13} \\ y_{22} & \sum_{x=1}^{n} y_{2x} & -y_{23} \\ y_{33} & -y_{32} & \sum_{x=1}^{n} y_{3x} \end{vmatrix}. \tag{16}$$

This suggests that an nth order determinant of similar structural form, such as Eq. 3, should have $(n + 1)^{n-1}$ terms. The truth of such a conclusion may be tested by means of mathematical induction through the use of the expansion of Δ that is given in Eq. 10. Each of the unsymmetrical minor determinants in Eq. 10 has the same structural form as Eqs. 11 and 16, and is of order $(n - 1)$. Therefore each unsymmetrical minor determinant in Eq. 10 should contain $(n + 1)^{n-2}$ terms in its expansion. The symmetrical minor determinant M_{11} may be seen from Eq. 6 to be factorable into the sum of two determinants, each of which is of order $(n - 1)$ and has the structural form exhibited in Eqs. 11 and 16. Therefore the expansion of M_{11} should contain $2(n + 1)^{n-2}$ terms. Since there are a total of $(n - 1)$ unsymmetrical and one symmetrical minor determinants in the expansion of Δ given in Eq. 10, the total number of terms to be expected is $2(n + 1)^{n-2} + (n - 1)(n + 1)^{n-2}$ or $(n + 1)^{n-1}$ terms. The assumption of applicability of the foregoing theory to the number of terms in the expansion of each of the minors in Eq. 10 leads to a prediction of $(n + 1)^{n-1}$ terms in the expansion of Δ. Therefore the principle of mathematical induction asserts that $(n + 1)^{n-1}$ is truly the maximum number of terms to be found in the expansion of a determinant such as that given in Eq. 2.

[4] The boldface numbers in parentheses refer to the references appended to this paper.

NUMBER OF TERMS IN THE EXPANSIONS OF DETERMINANTS OF ORDER $n-5$

In networks where one or more nodes are not directly connected to all of the other nodes by means of branches, the number of terms in the expansion of Δ is less than $(n+1)^{n-1}$. Where the network is sufficiently small that expansion of the determinant may be accomplished by determining the number of trees that the network possesses, it is therefore desirable to be able to predict how many terms the expansion should have. In order to show how the number of terms may be predicted, suppose that a network has n nodes exclusive of reference and that it contains B branch admittances. Each term in the expansion of the determinant must consist of the product of n of the B branches. The number of possible combinations $C(B,n)$ that may be formed from the B branches wherein each combination involves n of those branches is given by the following equation.

$$C(B,n) = \frac{B!}{n!(B-n)!}. \tag{17}$$

To find the number of terms in the expansion, the number of terms that involve closed loops must be deducted from the number of combinations $C(B,n)$. The number of such terms to be deducted may be found in the following manner.

Consider first an elementary loop that involves three branches. After a particular elementary loop has been selected, the remaining factors in a term of the expansion that contains this loop may be chosen from the remaining $(B-3)$ branches. Since the three branches that form the closed loop have already been chosen, a total of $(n-3)$ factors for the term must be chosen from the set of $(B-3)$ branches. Therefore the number of terms that contain the particular designated three-branch loop is obtained as follows as the number of combinations $C(B-3, n-3)$ of $B-3$ branches taken $(n-3)$ at a time.

$$C(B-3, n-3) = \frac{(B-3)!}{(n-3)!(B-n)!}. \tag{18}$$

If by inspection of the network, the total number of three branch loops is found to be L_3, the number of terms in which three branch loops are represented are given by $L_3C(B-3, n-3)$ where

$$L_3C(B-3, n-3) = L_3\frac{(B-3)!}{(n-3)!(B-n)!}. \tag{19}$$

If the number of nodes n is greater than five, a three-branch loop in addition to the particular designated loop may be found within the remaining $(B-3)$ branches from which the choice of the $(n-3)$ factors is to be made. Therefore Eq. 19 is valid only for $n \leq 5$. This does not impose

undue restriction, however, since a network with $n > 5$ is usually so complex as to render impractical the expansion of Δ by ascertaining by inspection the number of trees in the network.

If L_4 and L_5 represent the respective numbers of four- and five-branch loops that may be ascertained by inspection of the network, the number of terms in Eq. 17 that will contain these four- and five-branch loops may be shown in a manner similar to the foregoing development to be given by the following equations.

$$L_4 C(B-4, n-4) = L_4 \frac{(B-4)!}{(n-4)!(B-n)!} \tag{20}$$

$$L_5 C(B-5, n-5) = L_5 \frac{(B-5)!}{(n-5)!(B-n)!}. \tag{21}$$

The total number of terms to be obtained in the expansion of a determinant of the type given in Eq. 2 where $n \leq 5$ is obtained by deducting Eqs. 19, 20, and 21 from Eq. 17. This yields the following equation.

$$\text{Number of terms in the expansion of } \Delta = \frac{1}{(B-n)!} \times \left[\frac{B!}{n!} - L_3 \frac{(B-3)!}{(n-3)!} - L_4 \frac{(B-4)!}{(n-4)!} - L_5 \frac{(B-5)!}{(n-5)!}\right]. \tag{22}$$

EXTENSION TO THE COFACTORS OF Δ

In network theory, the cofactors of Δ are of frequent occurrence. The expansions of each of these may also be shown to consist wholly of positive terms. To demonstrate the truth of this assertion, consider the Δ_{1r} cofactor of Δ which is obtained by striking out the first row and rth column from Δ and by prefixing the appropriate algebraic sign:

$$\Delta_{1r} = (-1)^{r-1} \begin{vmatrix} \sum_{x=1}^{n} y_{1x} & -y_{12} & \cdots & -y_{1r} & \cdots & -y_{1n} \\ -y_{21} & \sum_{x=1}^{n} y_{2x} & \cdots & -y_{2r} & \cdots & -y_{2n} \\ \vdots & & & & & \\ -y_{r1} & -y_{r2} & \cdots & \sum_{x=1}^{n} y_{rx} & \cdots & -y_{rn} \\ \vdots & & & & & \\ -y_{n1} & -y_{n2} & \cdots & -y_{nr} & \cdots & \sum_{x=1}^{n} y_{nx} \end{vmatrix}. \tag{23}$$

The row bearing the row subscript r does not contain a summation. In order to show that Δ_{1r} has an expansion that consists of positive terms only, the row bearing row subscript r is shifted to the first row position in Δ_{1r}. The number of row interchanges that are encountered in this process is $(r - 2)$. If, furthermore, the negative sign on all elements in the first column of the resulting determinant is factored out, the algebraic sign in Eq. 23 must be multiplied by $(-1)^{r-1}$ to obtain the algebraic sign of the derived determinant. Since Eq. 23 already carries an algebraic sign of $(-1)^{r-1}$, the derived determinant must carry an algebraic sign of $(-1)^{r-1}(-1)^{r-1}$, which is always positive. Thus the derived form for Δ_{1r} is given by the following equation.

$$\Delta_{1r} = \begin{vmatrix} y_{r1} & -y_{r2} & \cdots & -y_{r,r-1} & -y_{r,r+1} & \cdots & -y_{rn} \\ y_{21} & \sum_{s=1}^{n} y_{2s} & \cdots & -y_{2,r-1} & -y_{2,r+1} & \cdots & -y_{2n} \\ \vdots & \vdots & & \vdots & \vdots & & \vdots \\ y_{r-1,1} & -y_{r-1,2} & \cdots & \sum_{s=1}^{n} y_{r-1,s} & -y_{r-1,r+1} & \cdots & -y_{r-1,n} \\ y_{r+1,1} & -y_{r+1,2} & \cdots & -y_{r+1,r-1} & \sum_{s=1}^{n} y_{r+1,s} & \cdots & -y_{r+1,n} \\ \vdots & \vdots & & \vdots & \vdots & & \vdots \\ y_{n,1} & -y_{n,2} & \cdots & -y_{n,r-1} & -y_{n,r+1} & \cdots & \sum_{s=1}^{n} y_{n,y} \end{vmatrix}. \quad (24)$$

Since Eq. 24 has the same structural form as Eq. 3, expansion of Δ_{1r} and therefore of all of the cofactors of Δ consists of a sum of positive terms.

CONCLUSIONS

The expansions of a determinant of the type given in Eq. 3 and of its cofactors have all been shown to consist of a positive sum of terms. The method of expansion has been demonstrated to precancel all negative terms which would be encountered by a straightforward Laplace expansion. The maximum number of terms to be obtained from the expansion of an nth order determinant such as Eq. 2 has been shown to be $(n + 1)^{n-1}$. The efficiency of the process may be appreciated as follows: All terms found in the expansion of such a determinant must be found within the products of the elements on the principal diagonal. The total number of such terms is n^n. Of these $(n + 1)^{n-1}$ are not canceled by terms formed from products of the elements off the principal diagonal. Thus the number of terms contained in the product of elements on the principal diagonal that are canceled by products of elements off the principal diagonal is $n^n - (n + 1)^{n-1}$. Since the canceled terms are found in the products of elements on the principal diagonal as well as off the principal diagonal, the total number of terms that are obtained in a straightforward Laplace expansion and that cancel are

$2[n^n - (n+1)^{n-1}]$. Thus the total number of terms obtained before canceling is $2[n^n - (n+1)^{n-1}] + (n+1)^{n-1}$ or $2n^n - (n+1)^{n-1}$. For a fourth order determinant with all coupling elements present, the total number of terms obtained by a straightforward Laplace expansion before canceling would be 387 of which $(5)^3$ or 125 would be noncanceling.

Acknowledgments

The aid of Professor H. L. Krauss of the Department of Electrical Engineering and of Professor William Mills in the Department of Mathematics at Yale University was greatly appreciated.

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THE FRANKLIN INSTITUTE

MINUTES OF THE SPECIAL MEETING

April 2, 1958

A Special Meeting of The Franklin Institute was held at 8:15 P.M. in the Lecture Hall. The President, Mr.Wynn Laurence LePage, called the meeting to order with approximately 150 members and guests in attendance. He announced that this Special Meeting had been approved by the Board of Managers in accordance with Article XI, Section 3, of the By-Laws, for the purpose of making the presentation of the Vermilye Medal Award for 1957, this award having been authorized by the Board of Managers at its Stated Meeting in November 1957 upon the recommendation of the Vermilye Medal Committee of the Board.

Mr. LePage recognized Mr. Francis J. Chesterman, member of the Board of Managers and Chairman of the Vermilye Medal Committee. After telling something about the Vermilye Medal, the founder of the Medal, the late William M. Vermilye, and the former recipients of this Medal, and reading the Citation, Mr. Chesterman presented the 1957 Medalist, Mr. Frederick C. Crawford, Chairman of the Board of Thompson Products, Inc. of Cleveland, Ohio, to the President for this award. The President presented the Medal and the Citation to Mr. Crawford and introduced him as the speaker of the evening.

Mr. Crawford's gracious and modest acceptance of the award was followed by a powerful talk on "An Experiment in Human Relations" telling of his thirty-five years' experience at Thompson Products, Inc., in labor-management relations. Mr. Crawford's talk was not only very interesting but his experiences and mastery of problems showed his complete knowledge and ability in the industrial management field. Members and guests acclaimed his talk with a spontaneous rising vote of thanks.

The President adjourned the meeting at 9:30 P.M. with warm thanks to Mr. Crawford.

WILLIAM F. JACKSON, JR.
Secretary

NOTE: The entire proceedings of this Special Meeting for the Presentation of the Vermilye Medal will be published in a later issue of the JOURNAL OF THE FRANKLIN INSTITUTE.

MINUTES OF THE STATED MEETING

April 16, 1958

The Stated Meeting of The Franklin Institute was held at 8:15 P.M. in the Lecture Hall. Mr. Wynn Laurence LePage, President, called the meeting to order with approximately 250 members and guests in attendance.

Mr. LePage reported that the minutes of the Stated Meeting of February 19, 1958, were published in the March issue of the JOURNAL. There being no corrections or additions, the minutes were approved as published. The minutes of the Stated Meeting of March 19, 1958, will be published in the April issue of the JOURNAL and will be presented for approval at the next meeting.

There being no further business, Mr. LePage announced it was his pleasure to introduce our honored guest and speaker of the evening. Mr LePage presented a brief background of Dr. Lux's academic and professional career and spoke of him as a young man who has helped mold the destinies of a small American company into one of national and international repute. Mr. LePage then introduced Dr. John H. Lux, President of the Haveg Industries, Inc., whose subject was "Plastics in the Space Age."

Dr. Lux spoke of the past developments in plastics and the outlook for the future, and of how the broader use of plastic materials and different units made from these materials will be used in the "Space Age." He used many illustrations as well as much exhibit material. Dr. Lux expressed the need for further basic research that would contribute to the development of new products and the establishing of new businesses, and the increased participation of small and medium sized organizations in the vast Government research and technical training program.

After generous applause Mr. LePage invited the audience to examine the many models and exhibit material on display and expressed The Institute's sincere thanks to Dr. Lux.

The meeting was adjourned at 9:30 P.M.

WILLIAM F. JACKSON, JR.
Secretary

COMMITTEE ON SCIENCE AND THE ARTS

(Abstract of Proceedings of Stated Meeting held Wednesday, April 9, 1958.)

HALL OF THE COMMITTEE,
PHILADELPHIA, APRIL 9, 1958.

MR. JOSEPH GRAY JACKSON in the Chair.

The following reports were presented for final action:

No. 3223: Development of the Magnetron.

This report recommended the award of a John Price Wetherill Medal each to H. A. H. Boot, J. T. Randall, and J. Sayers, of Birmingham, England, "For their basic developments which provided the first useful highpower pulsed microwave magnetron, and which established the fundamental principles upon which all later developments in this field were based."

No. 3340: The Franklin Medal.

This report recommended the award of The Franklin Medal to Donald Wills Douglas, of Santa Monica, California, "In recognition of his creative engineering in the field of aeronautical design as exemplified in all of his work but particularly in the DC series of transport airplanes which have become standard equipment on airlines throughout the world and have set the pattern of design in this field; and in recognition of his engineering genius which has provided inspired leadership for the technical developments of his industrial organization."

D. S. FAHRNEY
Secretary to Committee

LIBRARY

The Committee on Library desires to add to the collections any technical works that members may wish to contribute. Contributions will be gratefully acknowledged and placed in the Library. Duplicates received will be transferred to other libraries as gifts of the donor. 571 items have been added the past month.

Photostat service. Photostat prints of any material in the collections can be supplied on request.

The Library and reading room are open from 9 A.M. until 5 P.M. on Mondays, Tuesdays, Thursdays, Fridays and Saturdays; and 2 P.M. until 10 P.M. on Wednesdays. Beginning June 1, Saturday hours will be from 9 A.M. until Noon.

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The following elections were approved on April 3, 1958 by the Membership Committee by authority given to it by the Board of Managers.

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THE FRANKLIN INSTITUTE LABORATORIES
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THE "DECORATION" OF DISLOCATIONS IN α-BRASS

BY

RAYDONG SUN[1] AND HEINZ WILSDORF[2]

It has been known for several years that dislocations can be "decorated" by impurity atoms. This is usually done by adding a predetermined quantity of impurities in solid solution, straining and then heat treating. In metals, two processes are then possible: (*i*) The diffusion of impurity atoms to the dislocations, producing the so-called "atmospheres" and (*ii*) the nucleation of precipitates at dislocation sites. Through subsequent etching, the atmospheres or the precipitates, and thereby the dislocations, can be revealed. This technique makes it possible to investigate dislocation patterns on the original surface as well as in the bulk of the metal, because layers of determined thickness may be removed at will by electrolytic polishing. Since the distances between dislocations may be as small as a few hundred angstroms it is advantageous—and for detailed conclusions even necessary—to examine the specimens with an electron microscope.

The metal most extensively investigated so far has been aluminum, containing 1 to 5 per cent copper as the added impurity (1). It was found that slip bands, sub-boundaries and grain boundaries were preferred nucleation sites for the θ' phase of $CuAl_2$ precipitates. A detailed investigation of sub-boundaries established that the intersection of each edge dislocation with the surface of observation is marked by a precipitate (2). Furthermore, occasional dislocations, lying in the surface of observation, have been discovered in the form of closely spaced, parallel precipitates (3). This result was recently confirmed by Thomas and Nutting (4) and Takeyama and Koda (5). However, no detailed information as to the distribution of dislocations on active slip planes can be obtained with this metal, because of the very small distances between the slip lamellae in aluminum (approximately 300 Å) and the comparatively large precipitates.

In order to arrive at a clear picture of the arrangements of dislocations in slip lines, it was attempted to decorate dislocations in α-brass. This f.c.c. alloy has, at small elongations, a much coarser slip line structure than aluminum, and, therefore, it appeared to be a most promising material. In the following, the experimental technique used and some of the results obtained will be described briefly.

Spectroscopically pure copper and zinc were used to prepare a 70–30 brass to which 0.6 per cent cadmium was added. Polycrystalline and

[1] The career of this young and promising scientist on the staff of the Solid State Physics Division was terminated in February of this year, with his untimely death.

[2] Senior Staff Metallurgist, Solid State Physics Division.

single crystal specimens were quenched in iced brine from a temperature of 600° C. After a small elongation, the specimens were annealed for 2 hr. at 200° C. and polished electrolytically in order to reveal the now decorated dislocations. Finally, the surface was replicated and examined with the electron microscope.

Amongst others, results of considerable interest were obtained from a single crystal which had been elongated 4 per cent. Its surface was covered with etch pits which were immediately interpreted in terms of dislocations. They were arranged in rows, parallel to the active slip planes, as can be seen from Fig. 1, corresponding to a sequence of fairly

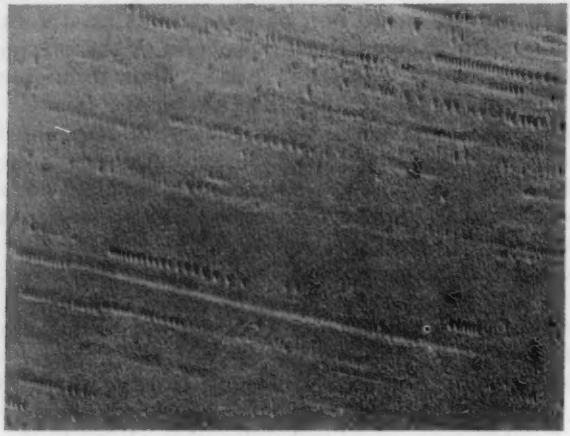

FIG. 1. "Decorated" dislocations in α-brass. 5600×.

closely spaced slip lines. One of the most obvious features of Fig. 1 is the presence of distinct dislocation groups. This is most interesting because, according to the theory of plastic deformation, dislocations in slip lines pile up against obstacles, and the observed groups obviously constitute such pile-ups. Fig. 2 shows one of them in detail.

Occasionally a pile-up is found which is so far removed from other dislocations that we may assume it has formed undisturbed from the

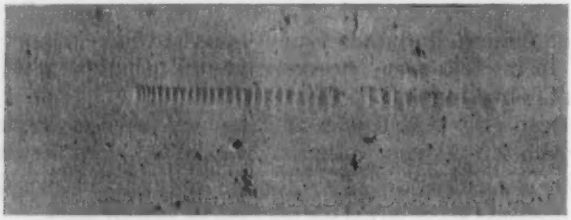

FIG. 2. Dislocation pile-up within slip line cluster. 7400×.

stress fields of neighboring dislocations, Fig. 3. With such a group we may test the accuracy of theoretical predictions concerning piled-up dislocations.

Eshelby, Frank and Nabarro (6) have shown that the length of a pile-up of dislocations, L, is given by $L = nGb/\pi\tau k$, where n is the number of dislocations, G the modulus of rigidity, b the Burgers vector, τ the acting stress and k a factor near unity. The pile-up in Fig. 3 contains 13 dislocations, packed into a length L of 5.7×10^{-4} cm. With $G = 4200$ kg./mm.^{2} and $b = 2.6 \times 10^{-8}$ cm. the stress τ is found as 1 kg./mm.^{2} which is in excellent agreement with experiment. Further, the ratio between the distance between the two leading dislocations, d_{min}, and that between the last two, d_{max}, by approximate formulae (7), is $d_{min}:d_{max} = 1.84:n^{4/3} \cong 1:17$. As the reader can readily ascertain, this ratio agrees with that obtained from the micrograph within the accuracy of measurement. This can be construed as both proof that the etch pits indeed mark dislocation sites, and proof that the theoretical calculations, applying elasticity theory, are close to the truth. Moreover, the theoretical concept that dislocations form pile-ups against ob-

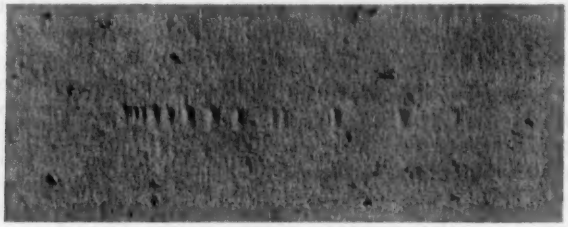

FIG. 3. Isolated dislocation pile-up. 7800×.

stacles in the course of plastic deformation is, again, substantiated. However, the fact that the pile-up in Fig. 3 has retained its original form until a replica was taken, is truly amazing. According to all current concepts, some rearrangement of the dislocations should have taken place already during the relaxation of the load after straining.

This research is being continued, and is supported by the Air Force Office of Scientific Research. We wish to thank Mr. L. Cinquina for his able help with the preparation of alloys.

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Do-It Yourself Satellite Pathfinder. —Newest do-it-yourself interest is connected with space travel. We may not yet be able to get to the moon, but we can track satellites and check their paths.

Now anyone can calculate precisely when a man-made earth satellite will pass overhead or over any particular spot in the Northern Hemisphere. A "Satellite Pathfinder" designed by Kenneth L. Franklin, associate astronomer at New York's American Museum-Hayden Planetarium, does the brainwork and no scientific training is needed by the user.

The device was designed by astronomer Franklin especially for the Young Adults' Division of the Library of Science, a new service providing quality and reliable modern science books and instruments for boys and girls of high school age. Like other materials provided to date to these budding young science geniuses, however, the Pathfinder has turned out to be a hot item for their mothers and dads.

The Pathfinder consists of two rotatable disks mounted on a base card. The top disk, made of clear acetate, has the orbital paths of the two Sputniks already printed on it, plus degree marks indicating latitude, and rows of dotted lines to help the user draw in the orbits of future satellites. The second disk, beneath the acetate one, is a map of the entire Northern Hemisphere with time zones printed around its edge.

This map disk is rotated beneath the acetate disk—a remarkably clear illustration of how the earth rotates beneath an orbiting satellite. In this way you plot an orbit from information given out by the radio and newspapers. Hours of the day and night are printed in a circle on the base card so that both disks can be accurately moved in time.

Each time a satellite is launched, information about its orbit is available from your local newspaper, museum or planetarium. To use the dog-carrying Sputnik II as an example: It was launched at an inclination of 65°, its direction of flight was NW to SE, and its orbiting period—the time to complete one revolution around the earth—was 102 minutes. That's all you need to know. The curve drawn through 65° indicates how its orbit appears on the acetate disk. Simply by knowing when the satellite passes over any spot, you can set the Pathfinder and use it to determine when the satellite will appear in your locality.

If you would follow a satellite for more than a day, move the acetate disk clockwise 15 min. after each 24-hr. period. This compensates for the orbit's *regression* or western drift. With care, a satellite's orbit can be plotted on the Pathfinder for weeks in advance.

THE BIOCHEMICAL RESEARCH FOUNDATION
ELLICE McDONALD, FOUNDER
WILLIAM G. BATT, DIRECTOR

COLORIMETRIC ESTIMATION OF D-GLUCOSE AND 2-DEOXY-D-GLUCOSE WITH GLUCOSE OXIDASE

BY

R. B. McCOMB AND W. D. YUSHOK

ABSTRACT

A modification of Keston's glucose oxidase method for D-glucose analysis is described. The glucose oxidase-peroxidase reaction was carried out in phosphate buffer, pH 5.9 at 45°, for 30 minutes. A clear stable color was developed by addition of sulfuric acid to a final concentration of 30 per cent. This acidification served as a convenient means of stopping the reaction and increased the sensitivity of the method. The method has been expanded for use in the analysis of 2-deoxy-D-glucose.

During the course of study of carbohydrate metabolism in this laboratory, it became necessary to analyze for glucose in the presence of other hexoses. This study was complicated by the fact that the usual chemical methods for the determination of reducing sugars are not specific for glucose. However, an enzymatic method which offsets this lack of specificity is the determination of glucose with glucose oxidase. This enzyme can be used for the quantitative analysis of glucose in the presence of all common hexoses except 2-deoxyglucose.

Glucose oxidase was first used for the specific manometric determination of glucose by Keilin and Hartree (1). More recently Keston (2) described a rapid and simple method for the determination of glucose in which peroxidase as well as glucose oxidase was used. The oxidation of glucose is catalyzed by glucose oxidase to form hydrogen peroxide which subsequently oxidizes dianisidine in the presence of peroxidase to an amber-colored product. Light absorption by this product is directly related to the original glucose concentration.

The Keston method has been modified and then used for the analysis of D-glucose in the presence of other hexoses in this laboratory. However it cannot be used in the presence of 2-deoxy-D-glucose since this sugar is also oxidized at an appreciable rate by glucose oxidase (3, 4).

When the original Keston method for glucose analysis was followed in this laboratory, a precipitate formed and the color which developed was unstable. This instability was presumably due to our use of unpurified preparations of glucose oxidase. We found that by suitable modification of the Keston method we could still use the crude commercial enzyme preparations without further purification.

Various reagents were added at the completion of the reaction in an attempt to stabilize the final color. It was found that the addition of concentrated sulfuric acid changed the color of the reaction mixture from amber to deep pink which was stable for at least several hours.

Moreover, this new color had a higher absorbance than the original amber color, hence the sensitivity of the analysis was increased. The addition of acid also became a convenient means of stopping the reaction.

The color development during the glucose oxidase-peroxidase reaction is proportional to the starting amount of glucose. For this reason the reaction can be stopped at any convenient time and the unknown glucose estimated by comparison with a glucose standard. If the reaction is allowed to go to completion, however, the timing and the amounts of the various reagents added become less critical and the final color is dependent only on the initial concentration of glucose.

2-Deoxyglucose in the absence of glucose can also be assayed by the same procedure. As with glucose, the color development is proportional to the starting concentration of the sugar. However, because of

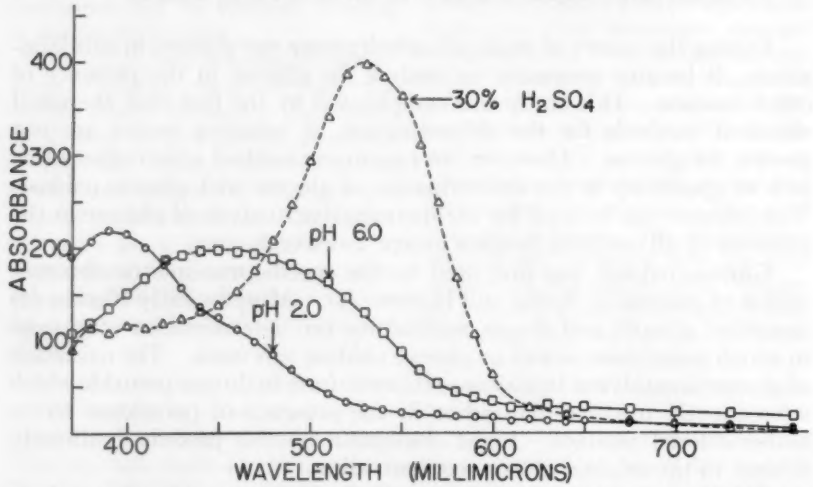

FIG. 1. Absorption spectra of glucose oxidase reaction mixtures under different conditions of acidity. The absorbances were determined by means of a Beckman DU spectrophotometer.

the much slower rate of oxidation the reaction does not go to completion within a convenient time, so that the 2-deoxyglucose assay must be carefully timed and compared to a standard analyzed simultaneously.

The velocity of the glucose oxidase reaction increased with temperature up through 45°, the highest temperature checked. At this temperature, the reaction went essentially to completion within 30 minutes at all glucose concentrations adaptable to the assay.

The pH selected for this modified procedure differs from that recommended by other workers (**2, 5**). A pH of 5.9 was used because this is a compromise between the pH optima of the two enzyme reagents, glucose oxidase and peroxidase.

The final color of the reaction mixture was found to be dependent

upon the acidity to which it was adjusted at the end of the reaction. The absorption spectra of the reaction products under various conditions of acidity are shown in Fig. 1. When the acidity of the final reaction mixture was pH 6.0, the spectrum exhibited a broad absorption band with a maximum at 450 mμ. When the acidity was changed to pH 2.0 there was a shift in the maximum absorbance to 390 mμ and a narrowing of the absorption band. When the absorbance was measured in 30 per cent sulfuric acid there was still another shift to a maximum at 520 mμ.

This dependence of absorbancy upon the final acidity of the analysis mixture made it necessary to carefully control the final acidity at low hydrogen ion concentrations. However, the absorbance of the reaction mixture was independent of the acidity at concentrations above 30 per cent sulfuric acid. The influence of sulfuric acid concentration upon absorbancy at 540 mμ (Klett filter 54) is illustrated in Fig. 2.

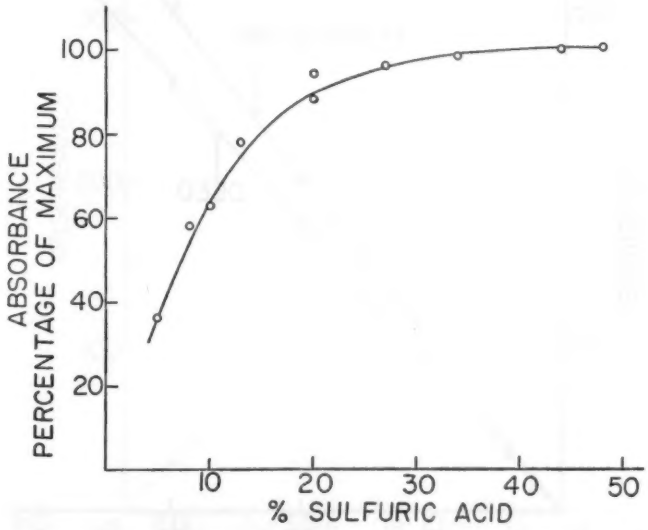

FIG. 2. Dependence of color development upon the final sulfuric acid concentration.

The final color which developed under the modified Keston procedure followed Beer's law over the whole concentration range. Standard curves for glucose in which two different commercial sources of glucose oxidase were used are illustrated in Fig. 3. The higher absorbance per micromole of glucose in the presence of Fermcozyme was due to the fact that this reaction went to completion in 30 minutes while that catalyzed by the Takamine product, Dee O, did not. A standard curve for 2-deoxyglucose is illustrated in Fig. 4.

The glucose oxidase method can be used to assay glucose in biological materials directly without preliminary treatment or can be applied to neutralized filtrates of the same material after treatment with the various protein precipitating agents. Because of the high specificity of this method it is particularly adaptable to enzymatic reactions which involve phosphate esterification or de-esterification of glucose. These phosphate esters are not substrates for glucose oxidase and do not interfere in the analysis. When this procedure was used for the measurement of disappearance of glucose in a hexokinase reaction mixture simultaneously with the less specific Nelson-Somogyi method for reducing sugars (6, 7), good agreement was obtained between the two.

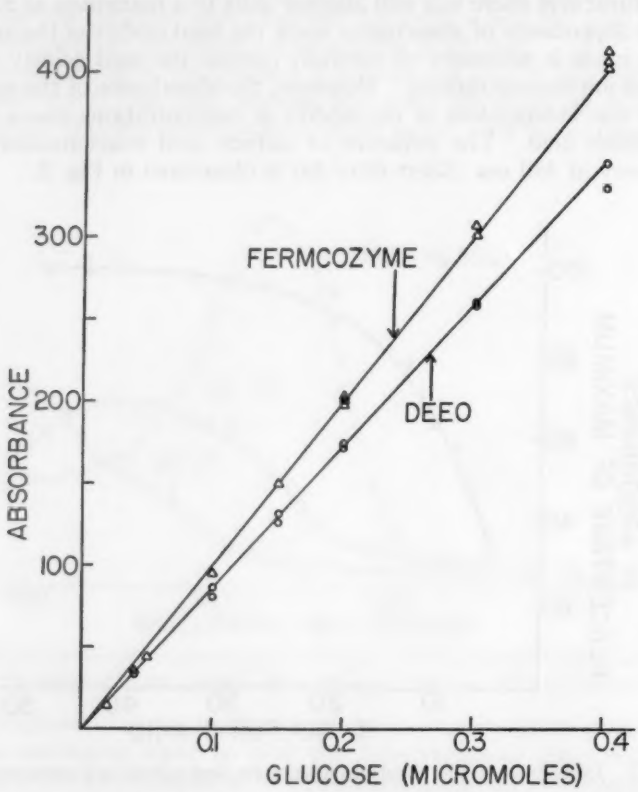

FIG. 3. Standard glucose curves. Dependence of absorbance upon glucose concentration under standard assay conditions for two different enzyme preparations. Absorbance measured with a Klett-Summerson photoelectric colorimeter, filter 54.

The reagents employed and the standard procedure as used in this laboratory for analysis of glucose and 2-deoxyglucose are described below.

Reagents

Peroxidase, 0.1%. Five mg. of Worthington horseradish peroxidase (600 units per mg.) is dissolved in 5.0 ml. of distilled water. This reagent retained its activity when stored at 4° for several months.

Dianisidine, 1.0%. One hundred mg. of *o*-dianisidine (Eastman Kodak T-509, recrystallized from ethanol) is dissolved by warming in 10 ml. of 95% ethanol. The solution is stored at room temperature and continues to give a low reagent blank absorbancy over a period of several weeks.

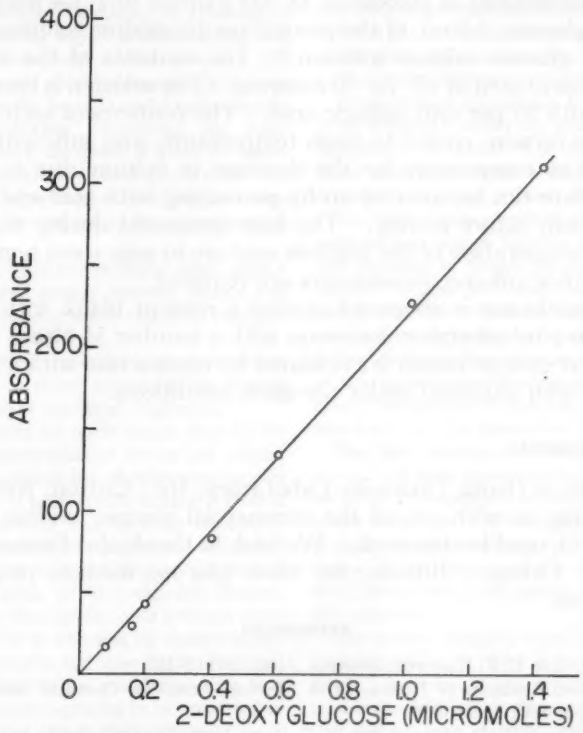

FIG. 4. Standard 2-deoxyglucose curve. Dependence of absorbance upon 2-deoxyglucose concentration under standard assay conditions. Absorbance measured with a Klett-Summerson photoelectric colorimeter, filter 54.

Peroxidase-dianisidine solution. To 1.0 ml. of 0.1% peroxidase is added 25 ml. of 0.4 *M* potassium phosphate, pH 5.9, followed by 1.0 ml. of 1.0% dianisidine. The resulting mixture is diluted to 100 ml. with distilled water.

Glucose oxidase, 1.0%. To 250 mg. of glucose oxidase, Dee O, a Takamine product (1500 units per gram), is added 25 ml. of distilled

water. The mixture is prepared fresh on the day of use and filtered. Very satisfactory results are also obtained with Fermcozyme, produced by Fermco Laboratories (750 units per ml.). This preparation affords added convenience because the enzyme is in solution and can be used directly by a simple 1 to 50 dilution of the commercial stock.

Procedure

Into each of a number of colorimeter tubes, graduated at 10 ml., are placed the following: 0.2–0.5 ml. of a sample containing 7–70 gamma (0.04–0.4 micromole) of glucose or 33–231 gamma (0.2–1.4 micromoles) of 2-deoxyglucose, 3.0 ml. of the peroxidase-dianisidine solution and 0.5 ml. of the glucose oxidase solution.* The contents of the tubes are mixed and incubated at 45° for 30 minutes. The solution is then diluted to 10 ml. with 50 per cent sulfuric acid. The contents of each tube are mixed by inversion, cooled to room temperature, and sufficient sulfuric acid added to compensate for the decrease in volume due to cooling. The procedure can be speeded up by precooling both acid and samples in an ice bath before mixing. The heat generated during the mixing brings the temperature of the analysis mixture to near room temperature and no further volume adjustments are required.

The absorbancy is measured against a reagent blank with a Klett-Summerson photoelectric colorimeter with a number 54 filter. The unknown sugar concentration is calculated by comparison with a standard which has been analyzed under the same conditions.

Acknowledgments

We wish to thank Takamine Laboratory, Inc., Clifton, New Jersey, for supplying us with one of the commercial glucose oxidase preparations, Dee O, used in this work. We wish to thank also Fermco Chemicals, Inc., Chicago, Illinois, for their glucose oxidase preparation, Fermcozyme.

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* The procedure may be further simplified by combining the peroxidase-dianisidine and glucose oxidase solutions in the proper proportions to form a single reagent. The combined mixture is stable if used on the day of its preparation.

BOOK REVIEWS

PROGRESS IN NUCLEAR PHYSICS, Vol. 6, edited by O. R. Frisch. 297 pages, diagrams, 6 × 9¾ in. New York, London, Paris, and Los Angeles, Pergamon Press, 1957. Price, $14.00.

Nine articles of a thorough nature are included in this volume dealing with several current phases of nuclear physics. Papers on nuclear masses cover the entire periodic table of the elements. Discussion is extended to excited states by way of articles dealing with spins, moments, and nuclear models. The most recent and reliable data relating to these topics are to be found in useful tables distributed appropriately throughout the book. Although much discussion is given to theory and to compilations of best values of nuclear constants, experimental methods are also treated, as, for example, in the case of isotopic enrichment.

Only special phases of high energy physics are discussed, namely mesonic atoms and those experiments which relate to non-conservation of parity.

Atomic physics and the solid state receive attention in a paper describing the slowing down process of the fission fragments.

The contents are made amply clear by the extensive presentation of curves and tabulations. A complete list of references appears at the close of each article so that if desired any given subject may be more intensively pursued. Opportunity is provided for a rapid and condensed understanding of the several important areas of investigation treated. Many of the discussions could generate ideas for research to be followed by those engaged in graduate studies and other forms of original activity. This volume could also serve as a source of interesting topics to be presented at colloquia before groups of physicists.

C. E. MANDEVILLE
Bartol Research Foundation

SOLID STATE PHYSICS, ADVANCES IN RESEARCH AND APPLICATION, VOLUME 5, edited by Frederick Seitz and David Turnbull. 455 pages, diagrams, 6 × 9 in. New York, Academic Press Inc., 1957. Price, $11.00.

The vast program of monographs on Solid State Physics undertaken by the editors of this series is progressing successfully and steadily. The first monograph of the Fifth volume due to J. P. Jan deals with Galvanomagnetic and Thermodynamic Effects in Metals. It starts out with the phenomenological theory and a classification (and definition) of the various effects. This is followed by the experimental results or magnetic-resistance, Hall effect and thermal conductivity and their theoretical interpretation. Special stress is put on ferromagnetic materials. The mode of exposition is very clear and thorough, and adequate references are provided.

In the second monograph, C. C. Klick and J. H. Schulman survey the phenomena of luminescence in solids. The authors classify these phenomena from a basic (and rather original) viewpoint. They distinguish between three types according to whether the luminescence process involves (*a*) absorption and emission in simple centers, (*b*) energy transfer without movement of charges, (*c*) charge transfer. While showing the striking advances made in the last decade towards a better understanding of luminescence, many of the unresolved difficulties (such as electronic transitions in sulfides, energy band structure, etc.) are pointed out.

The third monograph is devoted to space groups and their representation. A. F. Koster gives a competent and elegant treatment of this basic topic. A knowledge of the theory of group representation is assumed. A brief expose or at least summary of this theory would have been a very useful complement to this treatment.

The shallow impurity states in Si and Ge are analyzed by W. Kohn in the fourth monograph. A review of the experimental information available about these states (information derived from electron and nuclear spin resonance experiment, infrared absorption, magnetic susceptibility measurements, etc.) is followed by an exposé of the present status of the theory and a discussion of its success and failures. The last monograph written by M. H. Cohen and F. Reif, surveys the quadrupole effects in nuclear resonance studies of solids. The theory of electric quadrupole interactions is given at the outset with a full discussion of the quadrupole Hamiltonian, and

the method of calculation of field gradients in various types of crystal. The use of this "nuclear probe" of internal electric fields is abundantly illustrated, and the examples given are extremely instructive.

HENRI AMAR
The Franklin Institute Laboratories

MECHANICAL VIBRATIONS, by A. H. Church. 275 pages, diagrams, $5\frac{3}{4} \times 9$ in. New York, John Wiley & Sons, Inc., 1957. Price, $6.75.

Professor Church has produced an excellent introductory treatment of the vibrations of mechanical systems. It is written in a clear and comprehensible style, enhanced by generous use of diagrams, tables, and graphs. Examples are given to illustrate new principles as they are presented and symbols are well defined. Numerous problems (with answers!) are provided for the reader, who might profitably be either an upper class student or a practicing engineer meeting the subject for the first time. The examples and problems reflect the wide practical experience of the author. They also increase reader interest and simplify self study. References are not prolific but are adequate for a book at this technical level. They are introduced at pertinent points, either as part of the text or as footnotes. It would have been an added convenience for the student if they had also been collected in a bibliography.

The book contains the essentials of a first course in mechanical vibrations. The introductory discussion of harmonic motion and complex numbers is unusually good. The author then covers free and forced vibrations of one and two degree-of-freedom systems, including the effects of damping only for the single degree-of-freedom case. Vibration isolators, absorbers and simple measuring instruments are described. Multimass torsional systems without damping are discussed next with an explanation of the Holzer method. Practical information very helpful to the novice in the field is given on methods for obtaining equivalent masses, inertias and stiffnesses of real torsional systems. A clear exposition is then presented of three well-known methods (Rayleigh, Stodola, Prohl) for handling the undamped vibrations of multimass transverse systems. A qualitative discussion, with references, of the several factors affecting shaft critical speeds is included. Of merit is a practical resumé of the important subject of balancing. Basic principles are outlined and balancing machines are described briefly. A detailed outline is presented of the difficulties and procedures in balancing of both single-cylinder and multicylinder engines. The final chapter contains a limited discussion of electrical analogies. Although this extensive subject could hardly be covered in the present text, the lack of references is disappointing.

The publishers should be commended for a pleasing format, for printing which is large and sharp enough for easy reading, and for using low reflectivity paper.

This reviewer would not hesitate to recommend this book to anyone starting to study mechanical vibrations.

H. G. CLARKE, JR.
The Franklin Institute Laboratories

THE FUNDAMENTAL CONSTANTS OF PHYSICS, by E. R. Cohen, K. M. Crowe and J. W. M. DuMond. 287 pages, illustrations, 6×9 in. New York and London, Interscience Publishers, Inc., 1957. Price, $7.50.

For the scientist in need of an authoritative, fully documented treatise on the precisely determined physical constants, this book is essential. The authors have organized their material into clearly defined sections (chapters) which, with the fine Table of Contents and Index, makes the search for a discussion of the parameters, problems and pitfalls in determining any given fundamental physical constant relatively easy. Generally, then, the book provides information, data and references not readily available to any but the most careful and persistent bibliographers of this field.

The seventy-three page Chapter 4 on "Masses of Atoms and Mesons," with its 206 references (one-third of which are multiple) has an excellent summary of our present state of knowledge about mesons and "strange particles." From the detailed presentation and discussion, one is left with the impression that nuclear theory in the future is going to be as different as our present concepts of the structure of matter are from those enunciated by Dalton.

The care taken, in Chapter 5, in tracing the history of the atomic constants is outstanding. There is much to cogitate on relative to the

exactitude of Birge's methods for evaluating data on the atomic constants and the Isometric Consistency Chart currently in use by the authors (see the section starting on p. 163).

Chapter 7, concerning "The Method of Least Squares" is a fine summary of the authors' method of approaching "best" values for atomic constants. One interesting statement is that "best" choices can essentially be based on the Axiom of Maximum Likelihood: Of all the possible choices for the set of residuals (r_n), the best choice is that whose probability of occurrence is maximum."

In Chapter 8 on the "Least Squares Adjustment of the Atomic Constants," there is a good statement (p. 247) of the infinite care required in the analysis of data taken by different observers over a period of years and using different experimental techniques.

Only occasionally can one quarrel with the grammar and semantics. For example, on pages 2, 110, and elsewhere, the word "tract" is used to describe this "volume," that is, Volume I of the *Interscience Monographs in Physics and Astronomy*. Although the word "tract" does mean "exposition; literary treatment; also, a treatise; a dissertation, or a section of such," this usage is now rare and the word more commonly means "a pamphlet or leaflet issued by a political or religious group for propaganda; esp. one such containing a religious exhortation or a doctrinal discussion." This matter of semantics, the reviewer agrees, is almost inconsequential, yet its use serves to depreciate the book, relative to its erudition.

Over-all, the book will be a definitive document in the field of atomic constants for some years to come.

WILLIAM H. SULLIVAN
Oak Ridge National Laboratory

THE ORIGIN OF LIFE ON THE EARTH, by A. I. Oparin, translated from the Russian by Ann Synge. Third revised and enlarged edition. 495 pages, plates, 5½ × 8¼ in. New York, Academic Press, Inc., 1957. Price, $6.80.

In 1938 there appeared a book called "The Origin of Life" and its author was A. I. Oparin, who at the time was Associate Director, Biochemical Institute, USSR Academy of Science. The book was an instant success in that it filled a gap in the knowledge of man, dealing as it did with the origin of life.

The author for the first time had presented a complete and logical account as to how life on the earth could have been created. The author completely rejected the idea of spontaneous generation and the possibility of panspermy and concentrated on physical events which could have occurred on the earth.

He developed his theory by beginning with the formation of the primary carbon and nitrogen compounds. Then he went to the formation of the protein molecules and finally the formation of cells. His book was a classic which became a standard work for students.

However, in the intervening twenty years tremendous strides have been made in those facets of science which border life. Astronomy, geology, physics, chemistry and biology all play significant roles in the creation of life. Thus there arose the need for a revised and enlarged version of the original book and the present volume is that.

The author has expanded his book to include many of the experimental and the observational data which have come to light recently. It is impossible to point out a single item which ranks all the other data. This reviewer has a personal pet—the synthesis of the amino acids by Dr. L. S. Miller.

Each chapter is followed by an extensive bibliography. The index, however, is sadly deficient for a book of this type.

In his introduction the author writes: "The question of the emergence of life . . . raises a number of important and fundamental problems of natural philosophy. Every man, whatever his stage of development, has, consciously or unconsciously, put this question to himself and found some sort of answer to it, for without some such answer one cannot form even the most primitive picture of the world." In this book the author has given his answer and it makes intensely interesting reading.

The Origin of Life on the Earth is the ranking book on the subject and is a must for students in many sciences.

I. M. LEVITT
The Fels Planetarium of The Franklin Institute

NUMERICAL ANALYSIS, by Kaiser S. Kunz. 381 pages, diagrams, 6 ×9 in. New York, McGraw-Hill Book Co., Inc., 1957. Price, $8.00.

This is a text designed for a graduate course in numerical analysis. The reviewer enjoys

the unusual privilege (unusual, at least, for this reviewer) of reviewing a book from which he is currently teaching a course. This circumstance may tend to make one unduly critical, being swayed by minute details and failing to view the work justly as a contribution in the large. If such be the case, however, then even more so is *Numerical Analysis* by Kaiser S. Kunz to be considered a text successfully completing the purpose to which it is dedicated. This purpose, as stated by the author, is ". . . to acquaint the student with the best procedures available for obtaining numerical solutions to problems arising in applied mathematics . . . ." To present "the best procedures" one must be aware of recent developments in applied mathematics. That the author has this awareness is reflected in his bibliography and many references to contemporary writings.

Since his goal is a practical one, the author states the usual mathematics-text apology for lack of rigor, which lack of rigor will be noticed by relatively few who use the book and even fewer will be offended by it.

The scope of the book is as follows: Numerical solutions to algebraic equations, finite differences and interpolation, numerical differentiation and integration, numerical solutions to differential equations (ordinary and partial), simultaneous algebraic equations, and integral equations. Obvious omissions in a text of this kind are methods of smoothing data, least squares approximations and harmonic analysis. These omissions have made it possible for the author to present more thoroughly the topics that are included.

This is certainly not the only book of its kind but is, perhaps, more comprehensive than others covering the same scope. It is written clearly and the topics are introduced in an orderly and progressive manner. Mr. Kunz presents a diagrammatic scheme for representing all interpolation polynomials, numerical differentiation and quadrature techniques; the "lozenge diagram" can be used to derive new quadrature methods from known ones.

The reviewer recommends this book highly for those interested in a thorough understanding of the various topics of numerical analysis presented.

LAURENCE C. MCGINN
The Franklin Institute Laboratories

TEXTILE CHEMICALS AND AUXILIARIES, edited by Henry C. Speel and E. W. K. Schwarz. Second edition, 545 pages, diagrams, 6 × 9 in. New York, Reinhold Publishing Corp., 1957. Price, $13.50.

As the editors state in their preface, the object of their book is to cover as much of the textile field as is possible in one volume, pointing out the chemistry and chemicals used, rather than delving into mechanical processes per se. However, where a slight discussion of a particular mechanical process may serve to give better substance to an understanding of a particular subject, then this too has been included.

The book is divided into two main parts. Part 1, "The Nature and Processing of Fabrics," discusses the technological considerations and general processes used in the preparation of fibers and fabrics, dyeing, printing, finishing, fabric stabilization, and coating materials. Part 2, "Raw Materials in Fabric Processing," discusses the specific chemicals and materials used in the preparation of fabrics and in producing certain effects such as water resistance, flameproofing, and mothproofing. Emphasis on the material presented appears to have been placed on the practical aspects with some treatment given to the theories underlying the use of various chemicals.

As is the custom with edited books, each chapter has been written by an authority. Each author has submitted a bibliography for those who are interested in obtaining more complete information. All-in-all, a well written book which presents a wealth of information.

MARVIN PACKER
The Franklin Institute Laboratories

THE SCIENTIFIC STUDY OF SOCIAL BEHAVIOUR, by Michael Argyle. 239 pages, 5½ × 8½ in. New York, Philosophical Library, 1957. Price, $6.00.

This book is intended more as a guide to the procedures and results rather than as a textbook. It is intentionally not a treatise on social psychology since the fields of socialization and personality have been excluded. Argyle's development is divided into a section on methodology and a section on generalizations and theories.

Unfortunately the core of the book consists of a series of very brief summaries of the findings of various research workers. No effort was made, except for an almost trivial attempt at a morphology, to find emergent characteristics and to synthesize a theory. Thus the book becomes essentially an annotated bibliography which has certain large shortcomings. For example, no efforts are made to discuss any of the techniques of the last ten years which have attempted to mathematize sociometry and group decision processes.

In this reviewer's opinion a great deal more must be done in the development of mathematical schema for the organization of the data of social behavior before the adjective "scientific" may be applied properly to the study of social behavior.

EZRA S. KRENDEL
The Franklin Institute Laboratories

ON NUCLEAR ENERGY, by Donald J. Hughes. 263 pages, illustrations, 6 × 9 in. Cambridge, Harvard University Press, 1957. Price, $4.75.

We live in a revolution. Rarely, if ever, in the affairs of mankind have we been conscious of participating in a non-violent revolution. Yet with the advent of the atomic bomb and its dramatic offsprings, we need not wait for the fifty to a hundred years to become cognizant of the changes to which at this moment, we are subject.

Perhaps more effort has been expended on the atomic energy field than in any other in the history of man and it is a rare author who can capture the pulse of this facet of science and translate it in understandable language.

Dr. Donald J. Hughes of the Brookhaven National Laboratory, is eminently fitted to treat the nuclear energy field in its popular aspects. Essentially the book is a collection of lectures which the author has presented to lay groups and in his preface he indicates he was impressed with the eagerness and willingness of the public to learn. This has been the experience of many men in the field, but they all do not possess the versatility of Dr. Hughes to make interesting and intriguing the story of atomic energy.

The book is divided into nine chapters and most of these differ little from others which have appeared in the last twelve or thirteen years, except for the magnificent exposition on the part of the author. In the early part of the book he details the scientific background for the remainder of the book. This is done without formulae and makes fast reading.

The latter part of the book is the significant section to present day readers. The author deals with the production and use of isotopes in industry, medicine and agriculture. He probes the use of neutrons as tools for the research physicist. He discusses them in resolving some of the problems involving the fundamental particles of nature. The international aspects of atomic energy are covered. In this the author draws on his personal experience in his travels and lectures behind the Iron Curtain. He concludes with some aspects of safety and the security problem which makes the life of the AEC a difficult one indeed.

Some "loose" phrases have crept into what is otherwise an excellent book. The author states the temperature inside the sun for the fusion reactions to take place is well over a million degrees. Actually, inside the sun the temperature is perhaps twenty times this high. He speaks of the critical size of the atomic bomb. This critical size has become smaller and smaller and now is perhaps 10 per cent that of the Hiroshima bomb. In his discussion of the bomb, he avoids the implosion story. This is no longer secret and should be included in a current book on atomic energy. On page 35 he indicates the fusion of two deuterium atoms with an emission of 24 mev. Actually the probabilities of this reaction are low; however, on page 232 he indicates that this reaction is not practical for fusion.

These are minor comments which do not mar an outstanding book on this dramatic topic. Dr. Hughes has unquestionably produced a readable authoritative book which will enjoy wide circulation.

I. M. LEVITT
The Fels Planetarium of The Franklin Institute

BOOK NOTES

G. I. Taylor Scientific Papers. Volume One. Mechanics of Solids, edited by G. K. Batchelor. 539 pages, diagrams, plates, 6¾ × 10 in. New York, Cambridge University Press, 1958. Price, $14.50.

The pioneering work of G. I. Taylor in the field of mechanics of solids and fluids has been gathered together and edited and is now being published in volumes according to subject matter. This first volume contains all Taylor's studies on the mechanics of solids, including elasticity, plasticity, properties of metals and his work on dislocation theory. Some of these papers are here published for the first time. The remaining three volumes will cover various phases of the mechanics of fluids. In these volumes, typographical and minor mathematical errors in the original publication have been corrected; and the figures have been redrawn. The papers within each volume are arranged in chronological order.

Progress in Peaceful Uses of Atomic Energy, issued by the United States Atomic Energy Commission. 463 pages, illustrations, 4¾ × 9 in. Washington, D. C., Government Printing Office, 1958. Price, $1.25 (paper).

This volume is a three-year summary of the progress made in the peaceful uses of atomic energy. Part One consists of five chapters dealing with specific progress in radioisotopes, power reactors, international cooperation, the atomic energy industry and physical research —preceded by an introductory summary of the three years ending with 1957. Each of the five specialized chapters is subdivided and specific programs and activities are described. Of particular interest is the six-month period July-December 1957, when the first full-scale nuclear power plant designed exclusively for civilian electric power went into operation at Shippingport, Pa. Part Two covers the major activities of certain atomic energy programs in biology and medicine, construction, community operations, etc., as well as the military applications. Lists of the research contracts, patents, monitoring stations and a report on radioactive fallout comprise part of the useful appended material.

Polyamide Resins, by Donald E. Floyd. 230 pages, illustrations, 5 × 7¼ in. New York, Reinhold Publishing Corp., 1958. Price, $4.50.

One of the Plastics Applications Series being published by Reinhold, this volume is devoted to the basic chemistry and raw materials of polyamide resins. It includes, also, a description of the methods used in their manufacture and gives information on the important applications. After a preliminary discussion on the early development of polyamides, eight chapters are devoted to the resins and their applications (for example, coatings and films, adhesives, inks). A final chapter covers future trends in the use of these resins.

Science for All, prepared in consultation with The British Association for the Advancement of Science. 177 pages, 4¾ × 7¼ in. New York, Cambridge University Press, 1958. Price, $2.00.

This small book is an annotated reading list in the sciences for the non-specialist. Sixteen classifications (for example, mathematics, physics, geology) are given and under each there appears an alphabetical (by author) listing of the books on the subject which are intelligible to the non-specialist. The work is quite up-to-date, with 1957 books included. This is a most useful bibliography.

Safety Techniques for Radioactive Tracers, by J. C. Boursnell. 68 pages, 4¾ × 7¼ in. New York, Cambridge University Press, 1958. Price, $1.75.

All scientists working with radioactive isotopes—even in very small quantities—will do well to study this practical manual. The author explains the types of radiation and lists the possible dangers. He describes safety precautions and also the safety techniques to be used in the laboratory. The appendices (about a third of the book) include a classified table of isotopes and their toxicity, sketches of protective equipment, and shielding details. A bibliography of 47 references is divided into five general headings for further reading.

SCIENTIFIC SOCIETIES IN THE UNITED STATES, by Ralph S. Bates. Second edition, 6 × 9 in. New York, Columbia University Press, 1958. Price, $6.50.

The text of the first edition (1945) of this reference book has been brought up-to-date with the addition of Chapter VI entitled "The Atomic Age, 1945–1955," giving the changes in scientific societies since the close of World War II. Also, the bibliography has been completely revised and expanded. The new chapter emphasized the growing number of international organizations, particularly under the sponsorship of UNESCO.

GAS TURBINE MATERIALS, by G. Lucas and J. F. Pollock. 163 pages, diagrams, plates, 5½ × 8½ in. New York, The Macmillan Company, 1958. Price, $5.75.

This is a survey of the manufacture, properties and use of special materials for gas turbines. Prepared by two men experienced in the field, the book will be useful to designers as well as users, since it bridges the gap between metallurgical textbooks and those concerned primarily with design and performance. There are six main chapters, an appendix and an index. The authors are British; the materials described are generally designated in terms commonly used in England; the eighteen plates are all of British origin. However, the chapter references include American works and the American reader can "translate" the British alloys mentioned by referring to the Appendix giving the type and composition of the alloys.

TECHNIQUES OF MAGNETIC RECORDING, by Joel Tall. 472 pages, illustrations, 5½ × 8¼ in. New York, The MacMillan Company, 1958. Price, $7.95.

This is a book of magnetic recording practice. It is written by a man who has had a great deal of experience working with all kinds of magnetic recording devices over nearly all of the years that the subject has had commerical significance. Much of the book is devoted to descriptions of equipment, and this is done in some detail. With this information one with very little previous electronic experience could probably repair and maintain most commercial magnetic recording equipment.

There is also some information in Mr. Tall's book on the principles which make magnetic recording possible in its present form. However, having restricted himself in the depth to which he would go when discussing the physics of the subject, some of the most vital and interesting points must be by-passed with an apology.

One of the benefits to be derived from Joel Tall's book concerns a fairly large body of non-technical information on the history and uses of magnetic recording. Here the author describes interesting points about applications in music study, social behavior, speech therapy, psychiatry, cardiology, and measurements in numerous fields.

As an aid in teaching or learning the non-engineering aspects of magnetic recording this book is excellent. For the more detailed engineering aspects of the subject one should use as a complementary text S. J. Begun's book, "Magnetic Recording."

RADIOISOTOPES. A NEW TOOL FOR INDUSTRY, by Sidney Jefferson. 110 pages, illustrations, 5 × 7¼ in. New York, Philosophical Library, 1958. Price, $4.75.

Aimed at the layman, this book traces the development of industrial radioisotopes. In Part I on Industrial Applications, the author devotes eight chapters to descriptions of such applications (including leak detection, thickness measurements, gauges, etc.); Part II encompasses four chapters covering the elementary fundamentals of radioactivity. Businessmen will be interested in the variety of ways in which radioisotopes are being used—and they might even get an idea of how to use these new tools in their own line of work.

THE BIOTIC WORLD AND MAN, by Lorus J. Milne and Margery Milne. Second edition, 530 pages, illustrations, 7 × 9¾ in. New York, Prentice-Hall, Inc., 1958. Price, $7.50.

A second edition of this important volume on biological science. Beautifully illustrated with scores of photographs and written in almost "storybook" form, the book gives the authors' interpretation of what makes man the most successful organism on earth. An invaluable asset for the biology student, or for those just interested in the science of life forces and energy.

ADVANCED DYNAMICS, by John E. Younger. 285 pages, diagrams, 6 × 9 in. New York, The Ronald Press Company, 1958. Price, $8.50.

A volume especially prepared for students having completed junior-level courses in statics, dynamics, strength of materials, integral calculus and differential equations. The advanced character of the summary problems and the meticulous detail to the solutions, will satisfy the most ambitious student and make a valuable reference for practicing engineers.

THE PHYSICS OF CLOUDS, by B. J. T. Mason. 481 pages, diagrams, plates, 6 × 9¼ in. New York, Oxford University Press, 1957. Price, $11.20.

Although written primarily for the atmospheric physicist, this volume on cloud physics also contains much to interest those in the fields of nucleation phenomena, crystal growth and aerosol physics. Included in the text is a critical appraisal of the present status of rain-making experiments, as well as chapters detailing radar studies of precipitating clouds and the electrification of clouds. As a reference book for the student and research worker, it provides a detailed account of major developments in this important branch of meteorological physics.

PLASTIC SHEET FORMING, by Robert L. Butzko. 181 pages, illustrations, 5 × 7½ in. New York, Reinhold Publishing Corp., 1958. Price, $4.50.

This small reference book provides an introduction to sheet forming for the engineer and designer engaged in the field of plastics. Molds and mold design, the fabrication process, selection of materials and commercial machinery, along with production costs, are among the subjects discussed in the ten chapters. The text is clearly written so that the non-technical reader can evaluate the problems and potentials confronting the plastics industry.

ARCHITECTS' YEAR BOOK, edited by Trevor Dannatt. Eighth edition, 223 pages, illustrations, 7 × 9¾ in. New York, Philosophical Library, 1957. Price, $10.00.

This regular publication, not only addressed to professional architects, is profusely illustrated with beautiful photographs of architectural examples, scale models and cross-sectional building plans. Unlike most year books, it is not concerned with the presentation of statistics or summaries of trade developments, but rather with original thought and critical outlook, stimulating both to the creative architect and those less professionally involved.

HIGH-SPEED PHOTOGRAPHY, VOLUME 6. 200 pages, illustrations, 6 × 9 in. New York, Society of Motion Picture and Television Engineers, 1957. Price, $3.50 (paper).

This latest volume of the Society of Motion Picture and Television Engineers' reprint series contains articles on photographic equipment for guided missile research, light sources, electronic timing devices and the description of a tracking telescope type of optical recording instrument for missile programs.

POLYURETHANES, by Bernard A. Dombrow. 176 pages, illustrations, 5 × 7½ in. New York, Reinhold Publishing Corp., 1957. Price, $4.50.

In covering topics such as the chemistry, uses and applications, and handling of polyurethanes, a relative newcomer to the field of plastics, the author has produced a clear concise picture where this material fits into the field. However, perhaps he has been too brief in his treatment in some subjects. Apparently, the application of polyurethanes in foams is of special interest to the author since a fair portion of the book is devoted to it. He describes how foams can be tailor made from rigid to flexible types, their properties and applications.

This pocket sized edition is of value to technical and nontechnical personnel who wish to gain some insight into the potential of polyurethanes.

OFFICE AUTOMATION APPLICATIONS, by R. Hunt Brown. v.p., diagrams, 8½ × 11 in. (loose leaf). New York, Automation Consultants, Inc., 1957. Price: $37.50 (domestic and Canada); $42.50 (elsewhere).

The unusual format of this practical, easy-to-understand volume on automation in business practices emphasizes the rapid growth of the use of automation in business. The vol-

ume is loose leaf to allow for insertion of new pages (provided monthly by the publisher at a fee of $37.50 a year). Brightly colored plastic dividers make it easy to locate specific material in a hurry.

The book has four parts: I, General Considerations; II, Operations Research; III, Case Studies Sections (eight of them, for various types of business—manufacture of durable and non-durable goods, public utilities, petroleum products, finance and insurance, retail and wholesale trade, Government, and services; and IV, Summary and Index.

The major portion of the volume is devoted to Section III, the case studies of specific business firms. These case studies describe in detail the company's experiences with data processing and its plans for future use of automation. Pictures and flow charts accompany the text material.

PUBLICATIONS RECEIVED

The following books have been received in the JOURNAL office for review. Lack of space prevents publication of more than this listing.

THE PHYSICAL CHEMISTRY OF ELECTROLYTIC SOLUTIONS, by Herbert S. Harned and Benton B. Owen. ACS Monograph No. 137. Third edition, 803 pages, diagrams, 6 × 9 in. New York, Reinhold Publishing Corp., 1958. Price, $20.00.

MICRODIFFUSION ANALYSIS AND VOLUMETRIC ERROR, by Edward J. Conway. Fourth revised edition, 465 pages, diagrams, 5½ × 8½ in. New York, The Macmillan Company, 1958. Price, $8.50.

APPLICATIONS OF TENSOR ANALYSIS, by A. J. McConnell. (Formerly titled "Applications of the Absolute Differential Calculus.") Unabridged and unaltered reproduction, 318 pages, diagrams, 5¼ × 8 in. New York, Dover Publications, Inc., 1957. Price, $1.85 (paper).

THE TAYLOR SERIES, by P. Dienes. Unabridged and unaltered republication of the first edition, with errata incorporated into the text, 552 pages, diagrams, 5¼ × 8 in. New York, Dover Publications, Inc., 1957. Price, $2.75 (paper).

A TREATISE ON PLANE & ADVANCED TRIGONOMETRY, by E. W. Hobson. Unabridged and unaltered republication of the seventh edition of the work formerly titled "A Treatise on Plane Trigonometry," 383 pages, diagrams, 5¼ × 8 in. New York, Dover Publications, Inc., 1957. Price, $1.95 (paper).

MATHEMATICAL EXCURSIONS, by Helen A. Merrill. Unabridged and unaltered republication of the first edition, 145 pages, diagrams, 5¼ × 8 in. New York, Dover Publications, Inc., 1957. Price, $1.00 (paper).

INTRODUCTORY PHYSICS, by Herbert Priestley. 515 pages, diagrams, 7 × 9¾ in. Boston, Allyn and Bacon, Inc., 1958. Price, $7.50.

ELEMENTS OF MECHANICS OF MATERIALS, by Gerner A. Olsen. 536 pages, diagrams, 6 × 9 in. New York, Prentice-Hall, Inc., 1958. Price, $6.95.

OIL RESERVOIR ENGINEERING, by Sylvain J. Pirson. Second edition, 735 pages, diagrams, 6 × 9 in. New York, McGraw-Hill Book Co., Inc., 1958. Price, $14.00.

ELECTRON-TUBE CIRCUITS, by Samuel Seely. Second edition, 695 pages, diagrams, 6 × 9 in. New York, McGraw-Hill Book Co., Inc., 1958. Price, $10.50.

BASIC CONCEPTS IN CHEMISTRY, by George W. Watt. 538 pages, diagrams, 6 × 9 in. New York, McGraw-Hill Book Co., Inc., 1958. Price, $6.50.

SURFACE CHEMISTRY, by J. J. Bikerman. Theory and Applications. Second edition, 501 pages, diagrams, 6 × 9 in. New York, Academic Press Inc., 1958. Price, $15.00.

ION EXCHANGE RESINS, by Robert Kunin. Second edition, 466 pages, illustrations, 6 × 9 in. New York, John Wiley & Sons, Inc., 1958. Price, $11.00.

CURRENT TOPICS

Direct Ultramicrospectrography.—A valuable new research tool that enables scientists to measure fundamental chemical processes taking place within a living cell was described at the National Academy of Sciences recently by Professor Torbjorn O. Caspersson of the Nobel Institute for Medical Cell Research and Genetics, Karolinska Institutet, Stockholm, Sweden.

By integrating the most advanced developments in microscopy, spectrography and electronic scanning and computation, Professor Caspersson has been able to make quantitative analyses of substances as tiny as the gene-bearing structures within the cell. These heredity-determining elements would require, for normal weighing, scales sensitive to one hundred-trillionth of a gram. Even more important, these quantitative measurements can be made in sequence during different stages of cell growth and function.

From this new technique, called "direct ultramicrospectrography," may come not only new understanding of the inheritance of physical characteristics, but valuable weapons against cancer and virus diseases.

In describing his current work in virology, Dr. Caspersson said, "The interaction between the protein metabolic system of the host cell nucleus and an infecting virus has been studied within individual virus-infected cells. So apparent are the chemical changes within the cell that it is possible to observe the reaction of the host cell nucleus within one hour after the viral invasion."

At the present time, however, the most promising application of direct ultramicrospectrography may lie in a new understanding of the differences between normal and tumorous growth. In the Academy lecture, Dr. Caspersson referred to the underlying work in his laboratory in which optical cytochemical techniques were developed to determine the nature of minute biological substances by examining their absorption or refraction under monochromatic light. These earlier techniques were sufficient to demonstrate "intriguing differences" in the composition of populations of normal cells and tumor cells.

"Even though the optical cytochemical field offered great promise for the development of accurate analytical procedures," said Dr. Caspersson, "after several years of study, it seemed to be blocked by technical difficulties. One of the chief obstacles lay in the very great heterogeneity inherent in the biological material under examination."

"This difficulty," he continued, "was overcome by incorporating automatic scanning and computing devices within the instrumentation. Now, by measuring thousands of points in each cell, one can within a reasonable time obtain data representative for entire cell populations. Earlier, these problems were not within reach of cytochemical methods because long working periods were needed, during which the cells died.

"Automation has also made it possible to coordinate several instruments using various parts of the spectrum so that different analytical techniques can rapidly be applied in sequence to the same living cellular object.

"Recently our studies have shown

that among advanced tumor cell populations not only are there tremendous variations in composition, but also that the nature of this variation changes under the influence of such factors as chemotherapy and radiation.

"In many cases parts of the cells die and other parts are selected out to thrive under the new conditions. For instance, in an experimental *ascites* tumor under the influence of amethopterine, a special cell line is selected out, quite different from the original one. This demonstrates that the cytochemical analysis of tumor cell populations provides a way to study the mechanism of 'tumor progression,' a phenomenon which underlies sudden changes in growth rate, reaction to chemotherapy, and so forth.

"For the study of carcinogenesis the possibility of cytochemical population studies seems to be of value. Already, the limited studies made so far have revealed that these very great variances from normal cell populations exist even at early stages of tumor development. Further work may yield deeper understanding of the factors influencing tumor development and provide a diagnostic aid in the cytochemical identification of the very early stages of tumor growth."

New Process for the Electrorefining of Nickel.—Research scientists and engineers of The International Nickel Company of Canada, Limited, have developed a new process for the electrorefining of nickel, Ralph D. Parker, Vice President in Charge of Canadian Operations, has announced. He described the new method, developed after seven years of continuous study, as a major achievement in chemical metallurgy.

A main feature of the precess is the direct electrolysis of nickel matte, an artificial sulfide. This contrasts with the usual electrorefining methods, including those employed in the nickel industry, in which a metal anode is used. The new Inco process eliminates high-temperature oxidation and reduction operations, with attendant losses of metals and sulphur and selenium. Instead, nickel sulfide of low copper content from the Bessemer converter or other source can be cast directly into sulfide anodes and electrolyzed for the production of high quality nickel. Another unique feature of the process is that it permits, for the first time in nickel refining, the commercial recovery of elemental sulfur and selenium as valuable by-products, in addition to cobalt and precious metals conventionally recovered.

The process, for which Canadian and United States patents are pending, is in commercial operation in a section of the company's Port Colborne, Ont., nickel refinery. Sulfur-selenium separation is accomplished in a 100-ft. high fractionating column of special design.

The interesting possibilities of the new method were first demonstrated in Inco laboratory tests in 1951, when a small piece of cast nickel sulfide was electrolyzed. It corroded smoothly the nickel and other base metals passing into solution, leaving a precious metal-bearing anode sludge containing 97 per cent elemental sulfur.

A number of obstacles to the recovery of sulfur of high purity from the sludge were resolved by laboratory and pilot plant investigations. These studies, conducted jointly with Blaw-Knox Company, resulted in the construction of a novel 100-tons-per-day sulfur fractional distillation unit. The sulfur from this unit contains less than five parts per million of selenium and has an unusually low ash and bitumens content.

Ground Tests of Piasecki 59K VTOL.—Extensive ground tests of the Piasecki 59K VTOL (Vertical Take-Off and Landing) were recently conducted on a full-scale, full-power test model on a strain-gaged balance rig, mounted on the bed of a large trailer truck. Tests were run to determine thrust efficiency, and stability and control characteristics.

"The volume of data we have compiled on the 59K VTOL and on other ducted propeller programs, has enabled us to fully correlate our theories on the ducted propeller with actual test results," said F. N. Piasecki, President of the company.

The Piasecki 59K VTOL is a radical departure from previous VTOL designs. All major components—dual engine powerplant, rotors and controls—are housed compactly in the flat, low chassis, thus eliminating the large overhead rotor of the conventional helicopter, and greatly simplifying the drive assembly.

Lift is derived from two horizontal 3-bladed rotors, one at the front and one at the rear of the machine, just 3 feet above the ground. The operator's seat and passenger compartment are in the center section between the rotors. The rotors are completely shielded on all sides, an important new safety design feature. The entire chassis is supported on three wheels to provide ground maneuverability.

"In line with the increasing need for complete mobility, the Army requires a brand-new kind of vehicle that combines the utility of the ground jeep with the hovering and flying capabilities of a small helicopter," said Piasecki. "The 59K is designed to meet these requirements. Its ability to travel over any terrain, with or without roads, will make it a vehicle of inestimable value as a light utility transport, observation platform, or weapons carrier. Because of its low silhouette, the 59K can hug the ground, flying under bridges and wires, or behind low objects where concealment is desirable. Because of its compact design and protected rotors, the 59K can thread its way down narrow streets, between buildings, trees and other obstacles. It can be wheeled into cargo aircraft without disassembly."

Though the 59K is specifically designed to fly within sight of the ground, it will be capable of flying high enough to cross over most of the mountainous terrain in this country. Forward speeds over 150 miles per hour were envisioned by Mr. Piasecki.

Mr. Piasecki, who has been responsible for many pioneer designs in the field of vertical take-off aircraft, expects his company to have the first flying prototype ready for the Army early in 1958.

New Tensilized Polyester Film for Magnetic Tape.—A new type of thin gauge "Mylar" polyester film, with almost double the tensile strength of standard "Mylar," has been announced by the du Pont Company.

Developed as the result of several years' research, the tensilized film is designed primarily for use by the magnetic tape recording industry. All leading tape manufacturers plan use of the new type, known as 50 "Mylar" T, as a base for very thin tapes.

"By making possible durable tapes which provide more playing time per reel, the new high-strength film will increase the versatility of tape in the audio field," according to J. Edward Dean, director of sales for the company's Film Department.

The increased yield strength, as well as tensile strength, offers improved performance for the so-called "double-play" tapes. These double-length

tapes provide 2400 ft. of tape on a 7-in. reel—about twice the footage offered by tapes based on 1½-mil cellulose acetate or 1½-mil "Mylar." At a speed of 7½ in. per second, this represents two hours of playing time on a double-track recorder.

The increase in strength was accomplished without sacrifice of other important film properties. The new 50 "Mylar" T, like standard "Mylar," can be stored indefinitely. It is not affected by moisture and temperature extremes (from −80° to 300° F.) or subject to embrittlement.

Standard one-mil "Mylar" polyester film, strong enough to provide an ample margin of safety under normal recording use, still will be recommended for applications where the extra playing time afforded by 50 "Mylar" T is not an important factor.

Nuclear Reactor Core Instrumentation.—Teleflex Incorporated, manufacturers of flexible precision mechanical remote controls, held a press preview and demonstration of their new Nuclear Reactor Core Instrumentation at the North Wales, Pennsylvania plant on March 3, 1958. An actual demonstration of the Activation Wire Drive System was given. The Activation Wire Drive instrumentation system is used to ascertain neutron flux and fuel distribution information from a reactor core. The primary function of this instrumentation is to obtain test data which are relative to the performance of the reactor and which will provide a basis for calculation of fuel burn-up history.

Specifically, the following three distinct functions are performed by this equipment: (*a*) Measurement of steady-state thermal neutron flux distribution throughout the reactor core; (*b*) Measurement of fuel distribution among specified core locations during burn-up; and (*c*) Continuous indications of instantaneous thermal neutron flux values at specific locations within the core.

Through the use of Teleflex flexible cable both activation wires and neutron-sensitive thermocouples may be inserted from a remote location, down into the reactor core while the reactor is in operation, thus eliminating the need to shut down the equipment for test purposes. Stainless Steel conduits or thimbles are routed, as desired, within the reactor to form the path in which the cable operates. Auxiliary positioning, recording, and scanning devices are also utilized.

Liquid Brake System for Aircraft.—A new liquid-cooled brake system for aircraft that prevents temperature build-up on braking surfaces by as much as 1500° has been announced by Air Force and B. F. Goodrich Aviation Products officials. It was developed for the Air Force under sponsorship of the Air Research and Development Command.

This is the first practical braking system for aircraft to use fluid for reducing excessive heat in the braking area. The revolutionary disk-type brake, developed and engineered for aircraft removes heat from the critical wheel and brake area and carries it to a point where it can be dissipated at low temperatures. This is not simply a brake but a completely new brake system that reduces high temperatures generated in aircraft landings.

Tests conducted by ARDC's Wright Air Development Center showed that the brake performed consistently without fade in consecutive stops, operating at maximum temperatures below 500° F. Brake performance was tested at landing speeds ranging from 60 to 160 miles per hour. At full static engine run-up, before and fol-

lowing the tests, the new brake reportedly held the aircraft at zero velocity.

Weight of the liquid-cooled brake system is about the same as for standard brakes now in use. It is claimed that weight savings can be made when the airplane has been designed to utilize this new brake through simplification of system components. In addition, lower spin-up loads reportedly allow further weight savings in landing gear structures through use of higher heat-treat materials.

According to ARDC and Goodrich project engineers, conventional brakes of the drum or disk type, are approaching their maximum heat capacity on new high-performance aircraft which operate at supersonic speeds. The storage of extremely high energy within the housing of those brakes results in heat transmission and possible damage to wheels, tires, axles and struts.

The new brake system which utilizes a coolant fluid to transmit generated heat to a heat exchanger, is said to lower brake wear, require less maintenance and greatly improve the safety factor.

Additional tests will be conducted shortly on the prototype Boeing 707 jet transport.

Color Standards for Panel Tubing.—A color code for panel tubing has been established by experts under the supervision of the Instrument Society of America. This set of standards is the twenty-second of the so-called Recommended Practices regularly put out by ISA. Like the others, it specifies uniformity in a certain segment of design manufacture, or application of control instruments.

ISA recommends uniform color coding of pneumatic tubing on instrument panels in this four-page study. In essence the code urged for industry-wide adoption is this: air supply—red, seal—purple, set—black, alarm—green, readout—blue, transmitted—orange, controlled—yellow, all others—natural.

A need for standardization of colors in instrument panel work has been apparent for years. A survey conducted by ISA revealed that color coding was in wide use, but that there was no uniformity in selecting a given color for a given service. The new set of approved standards will permit quick identification of tubing circuits throughout industry.

Miniaturized Pulse Transformer Line.—A complete series of miniaturized Pulse Transformers has been announced by the Computer Components Division of International Resistance Company Philadelphia, Pa.

Packaged in a special moisture resistant epoxy resin, these small transformers are designed with a 7-pin miniature plug-in base or with leads for soldering to printed circuit boards. Stock transformers offer a wide variety of electrical characteristics. Prototype service is available to supply special designs tailored to specific applications.

These transformers are designed for use in blocking oscillators, impedance matching, phase inversion, interstage coupling, triggering and counting circuits.

Boron Rocket Fuels.—University of Michigan chemists have been working since 1952 on the "ground rules" for the development of the new high-energy boron rocket fuels.

Robert Parry, associate professor of chemistry, said that he and his associates have been conducting a long-range study of the basic properties of boron-hydrogen compounds for the

Air Force's Wright Air Development Center through the University's Engineering Research Institute.

Boron fuels have recently been identified as one of this country's major new rocket propellants. The Air Force has also ordered a 2000-mile-an-hour "chemical bomber" which will use a super-strong compound containing boron.

Professor Parry pointed out that boron compounds are made up of relatively light elements which release far more energy than conventional petroleum fuels when they burn, providing as much as one and one-half to two times as much thrust per pound. Many of the boron-hydrogen compounds are unstable materials which have had to be "tamed" before they could be put to work as practical fuels.

Because the compounds burn so violently in the presence of air or water, they are prepared and studied by Professor Parry and his colleagues in elaborate vacuum systems. Here boron hydride compounds are mixed with a variety of bases such as ammonia under controlled temperatures and pressures. A reaction occurs, and the chemists then purify the product and chart its properties, all within the vacuum system.

"Our primary interest is in the fundamental properites of these compounds," Professor Parry said. "If the compounds lend themselves to use as fuels, that is incidental. But I think it is fair to say that work of this nature here and at other laboratories is absolutely essential to the development of high-energy fuels."

By charting properties of boron compounds, the U-M chemists have helped give fuel developers a starting point, just as U-M metallurgists measuring the properties of metals at high temperatures have aided designers of gas turbine and rocket engines.

Because of his knowledge of boron compounds, Professor Parry has served since 1953 as a consultant to the Callery Chemical Co., makers of the new fuel.

In some cases, the U-M chemists create compounds at temperatures as low as 140° below zero because the compounds would decompose at higher levels, Professor Parry said. And because of the danger involved, they work with only small amounts of material—as little as five hundredths of a gram, or about one ten-thousandth of a pound.

Professor Parry points out that there are so many possible compounds to be tested under so many conditions that he has enough work to keep him busy "for the rest of my natural life."

Electronics to Start Revolution in Office.—"American business is facing a revolution in office methods that can surpass the changes wrought by the typewriter, the adding machine and the punched card."

And, said electronics expert John E. Johnson, industry and business can literally eliminate the hundreds of paper forms that create "a blizzard of paperwork in the in-between stages from order to delivery" if it harnesses the full potential "brain-power" of electronic computer systems.

Johnson, who is vice president of marketing for the Datamatic division of Minneapolis-Honeywell Regulator Co., explained that by using "electronic brain" systems to their maximum capabilities it would be possible to eliminate all but the original piece of paper, an order, for example. Everything else—all the intermediate reports—would be transmitted electronically.

Speaking before a meeting of the Twin Cities chapter of the Controllers Institute of America, St. Paul, Minn.,

Johnson described a system wherein Company A, purchasing from Company B, would have no need for such paper forms as purchase orders, invoices, receiving reports, checks or deposits. If both companies had electronic systems, he said, they could electronically debit "accounts payable" at Company A and credit "accounts receivable" at Company B, simultaneously crediting and debiting cash respectively at their banks.

True office automation of this type, or "total data processing" as he calls it, has thus far been held back by the duplication of record-keeping that exists among accounting, sales and production departments and by businesses' tendency "to parallel decentralized operations with decentralized data-processing units," he said.

Today, however, the electronic systems on the market make it possible to establish a centralized processing system fast enough to meet the needs of sales, production and accounting, Johnson said, and this opens a vast new area for elimination of duplication of effort.

"Companies should understand that a large-scale electronic data-processing system which leases for $40,000 a month is not merely twice as efficient as two medium-size systems which lease for $20,000 each, but five or ten times as efficient," he declared.

The next big step, and one which will accelerate total data processing as much as anything else, is "the improvement in communication between man and the machine," he predicts.

Devices are now being perfected that can read the "same kind of numbers and characters" that people read and write, Johnson explained. They will solve the long-standing problem of translating business work from human to machine language, eliminating the big time gap and expense of the translation process.

And it also means, Johnson added, that the days of the punched card as a business document are numbered.

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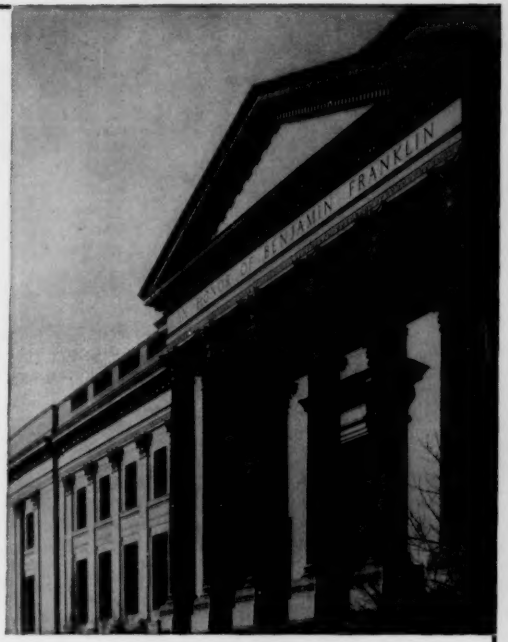

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